Name	Candidate Number

Anglo-Chinese School
(Independent)

YEAR 6 PRELIMINARY EXAMINATION 2023
INTERNATIONAL BACCALAUREATE DIPLOMA PROGRAMME
CHEMISTRY HIGHER LEVEL

PAPER 2

Wednesday **13th September 2023** **2 hours 15 minutes**

INSTRUCTIONS TO CANDIDATES

- Do not open this examination paper until instructed to do so.
- Write your **candidate session number in the box above**.
- A calculator is required for this paper.
- A copy of the Chemistry Data Booklet is required for this paper.
- Write your answers in the boxes provided.
- If you use additional sheets of paper for your answer, attach them to the booklet. Indicate the question number clearly on these sheets.
- All drawings must be in ink.

For examiner's use	
Qn 1	/6
Qn 2	/22
Qn 3	/8
Qn 4	/10
Qn 5	/13
Qn 6	/9
Qn 7	/15
Qn 8	/7
Wrong s.f. /units	
Total	/90

This question paper consists of 31 printed pages including this cover page.

Answer **all** questions. Write your answers in the boxes provided.

1. Carbon consists of 4 allotropes in the form of diamond, graphite, fullerene and graphene.

(a) State and explain the difference in electrical conductivity of diamond and graphite. [2]

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(b) Explain why the carbon-carbon bonds in graphite are stronger than the carbon-carbon bonds found in diamond. [2]

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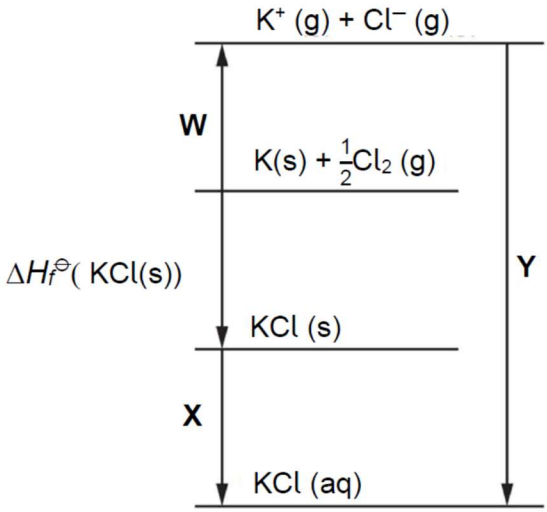
(Question 1 continued)

(c) State the type of hybridization of the carbon atoms in diamond and graphite. [2]

Diamond: ……...

Graphite: ……

2. The energy cycle shown can be used to calculate the enthalpy change of formation of KCl (s). Each arrow indicates a transformation, **W**, **X**, and **Y.** Each transformation consists of one or more steps.



(a) (i) Calculate the value of the following transformations using section 8 of the data booklet and the following information. [4]

Enthalpy change of atomisation of K (s)	+89 kJ mol^{-1}
Enthalpy change of atomisation of Cl_2 (g)	+121 kJ mol^{-1}
Enthalpy change of solution of KCl (s)	−17 kJ mol^{-1}
Enthalpy change of hydration of Cl^-(g)	−365 kJ mol^{-1}
Enthalpy change of hydration of K^+(g)	−340 kJ mol^{-1}

(This question continues on the following page)

(Question 2 continued)

Transformation **W**: $K\ (s) + \frac{1}{2}Cl_2\ (g) \rightarrow K^+\ (g) + Cl^-\ (g)$

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Transformation **Y**: $K^+\ (g) + Cl^-\ (g) \rightarrow KCl\ (aq)$

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(ii) Using your answer to **(a)(i)** and the given data to calculate the enthalpy change of formation of KCl (s). [2]

If you did not get answers to **(a)(i)**, use +200 kJ mol^{-1} and –650 kJ mol^{-1} for **W** and **Y** respectively, but these are not the correct answers.

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(This question continues on the following page)

(Question 2 continued)

(a) **(iii)** State and explain the sign for the entropy change for the formation of KCl (s). [1]

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(iv) Deduce, giving reasons, whether altering the temperature would change the spontaneity for the formation of KCl (s). [2]

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(b) Explain why the enthalpy change of hydration of K^+ is less exothermic than that of Ca^{2+}. [1]

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(Question 2 continued)

(c) **(i)** Explain why the ionic radius of K^+ is smaller than that of Cl^-. [2]

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(ii) Explain the decreasing trend in the first ionization energies of Group 1 and Group 17 elements down the group. [1]

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(This question continues on the following page)

(Question 2 continued)

(c) **(iii)** The Periodic Table groups together elements with similar properties. In most Periodic Tables, hydrogen is placed at the top of Group 1, but in some it is placed at the top of Group 17. [2]

Using your knowledge of chemistry, state one reason for hydrogen being placed above either Group 1 or Group 17.

Reason why hydrogen is placed above Group 1:

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Reason why hydrogen is placed above Group 17:

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(iv) The hydrogen spectrum data can give information on the frequency for its convergence limit. Using sections 1, 2 and 8 of the data booklet, calculate the frequency of the photon to remove 1 mol of electron from 1 mol of gaseous hydrogen atoms. [2]

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(This question continues on the following page)

(Question 2 continued)

(d) Chloride ions can act as ligands. When concentrated hydrochloric acid is added to a solution containing pink $[Co(H_2O)_6]^{2+}$, a blue solution of $[CoCl_4]^{2-}$ is formed and the following equilibrium is established.

$$[Co(H_2O)_6]^{2+} + 4Cl^- \rightleftharpoons [CoCl_4]^{2-} + 6H_2O$$

(i) Complete the electronic configuration of Co ion in $[CoCl_4]^{2-}$. [1]

$1s^2$.....

(ii) Use Le Chatelier's principle to suggest the expected observations when silver nitrate solution is added dropwise to the blue solution of $[CoCl_4]^{2-}$. Explain your answer. [2]

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(Question 2 continued)

(d) (iii) Bubbling air through different aqueous mixtures of $CoCl_2$, NH_4Cl and NH_3, produces various complex ions with general formula $[Co(NH_3)_{6-n}Cl_n]^{3-n}$. [2]

Determine the oxidation state of cobalt and the type of bond formed in these complex ions.

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3. **(a)** Hydrogen iodide can be made by heating hydrogen gas and iodine vapour in a reversible reaction.

$$H_2\,(g) + I_2\,(g) \rightleftharpoons 2HI\,(g)$$

(i) Determine the standard enthalpy change, ΔH, for the reaction, using section 11 of the data booklet. [2]

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(ii) Enthalpy change of reaction calculated using bond enthalpy values usually deviate from the literature value. However, the enthalpy change calculated in **(a)(i)** coincides with the literature value. Explain why this is so. [1]

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(This question continues on the following page)

(Question 3 continued)

(b) At 400 K, the rate constant for the forward reaction is approximately 1000 times greater than the rate constant for the backward reaction. The overall orders of the forward and backward reactions are the same. [2]

Forward reaction: H_2 (g) + I_2 (g) $\rightarrow$ 2HI (g)

Backward reaction: 2HI (g) $\rightarrow$ H_2 (g) + I_2 (g)

Use this information to explain what will happen if equal concentrations of HI (g), H_2 (g) and I_2 (g) are mixed at 400 K.

You should comment on:

- The relative initial rates of the forward and backward reactions
- The position of the equilibrium reached.

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(c) **(i)** At exactly 700 K, the value of the equilibrium constant is 56. Calculate the ΔG, Gibbs free energy change for the reaction, in kJ per mole, using sections 1 and 2 of the data booklet. [1]

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(This question continues on the following page)

(Question 3 continued)

(c) (ii) When 0.218 mol sample of hydrogen iodide was heated in a flask of 2 dm^3, the equilibrium was established at 700 K. [2]

Calculate the equilibrium concentrations of hydrogen and iodine.

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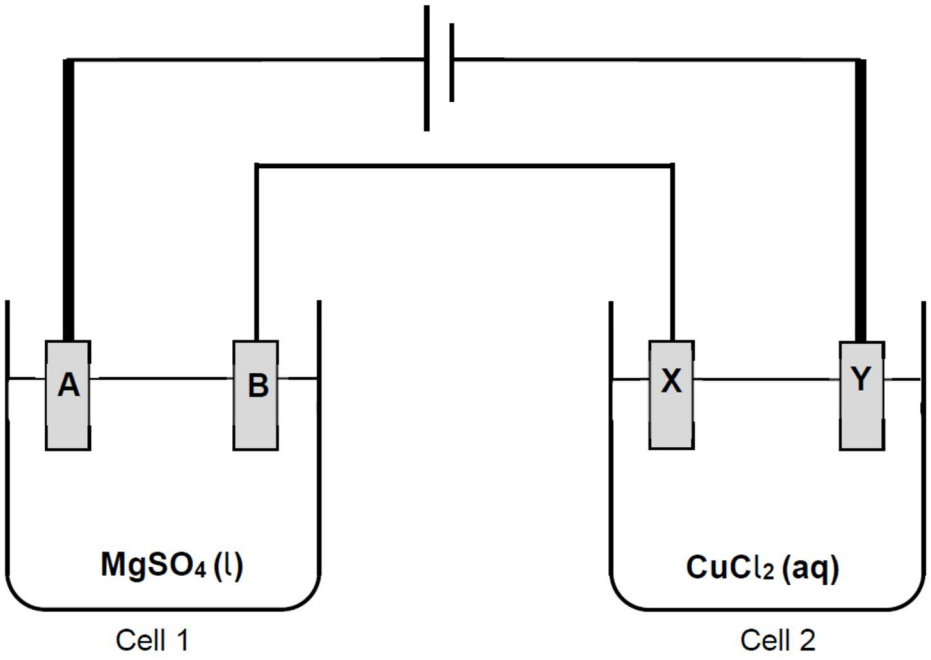
4. (a) The diagram below shows two electrolytic cells connected in series. Concentrated $CuCl_2$ (aq) is used as the electrolyte and graphite electrodes are used.



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(Question 4 continued)

(a) (i) Cell 2 is intended for copper-plating a coin. Write the half-equations of the reactions occurring at electrodes **X** and **Y**. [2]

Reaction occurring at electrode **X**: .....

Reaction occurring at electrode **Y**: .....

(ii) As the copper plating process was occurring in Cell 2, 4.52 g of Cu was plated on the coin after 10 minutes. Identify the product formed at electrode **B** and calculate the mass of the product formed at electrode **B** after 10 minutes. [2]

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(b) The standard electrode potentials of four half-cells are given below.

	$E^{\ominus}$/**V**
$Zn^{2+}(aq) + 2e^- \rightleftharpoons Zn(s)$	−0.76 V
$V^{3+}(aq) + e^- \rightleftharpoons V^{2+}(aq)$	−0.26 V
$VO^{2+}(aq) + 2H^+(aq) + e^- \rightleftharpoons V^{3+}(aq) + H_2O(l)$	+0.34 V
$VO_2^+(aq) + 2H^+(aq) + e^- \rightleftharpoons VO^{2+}(aq) + H_2O(l)$	+1.00 V

(This question continues on the following page)

(Question 4 continued)

(b) **(i)** Deduce the balanced equation, **including state symbols**, for the overall reaction with the greatest standard cell potential, $E^{\ominus}_{cell}$ and calculate the standard cell potential, $E^{\ominus}_{cell}$. [2]

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(ii) Calculate the value of $\Delta G^{\ominus}$ using your answer in **(b)(i)** in kJ mol^{-1}. [2]

(If you did not obtain an answer to **(b)(i)**, use 1.55 V, but this is not the correct value.)

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(This question continues on the following page)

(Question 4 continued)

(c) Electrochemical or voltaic cells were introduced as a tool for studying the thermodynamic properties of fused salts more than a century ago. A voltaic cell that converts chemical energy into electrical energy. Corrosion of iron is like the processes that occur in a voltaic cell. The initial steps involve the following half-equations: [2]

$$Fe^{2+}(aq) + 2e^- \rightleftharpoons Fe(s)$$

$$\tfrac{1}{2}\, O_2(g) + H_2O(l) + 2e^- \rightleftharpoons 2OH^-(aq)$$

An iron half-cell, $Fe(s)/Fe^{2+}(aq)$, can be connected to a hydroxide half-cell, $O_2(g)/OH^-(aq)$.

Draw a diagram of the voltaic cell under standard conditions. Label the polarity of the electrodes, voltmeter, electron movement, and information on the electrodes and electrolytes used.

5. A 0.25 mol dm^{-3} ethylamine solution is prepared and it has a pH of 12.0.

(a) Suggest, with suitable calculations, if ethylamine is a strong or weak base. [2]

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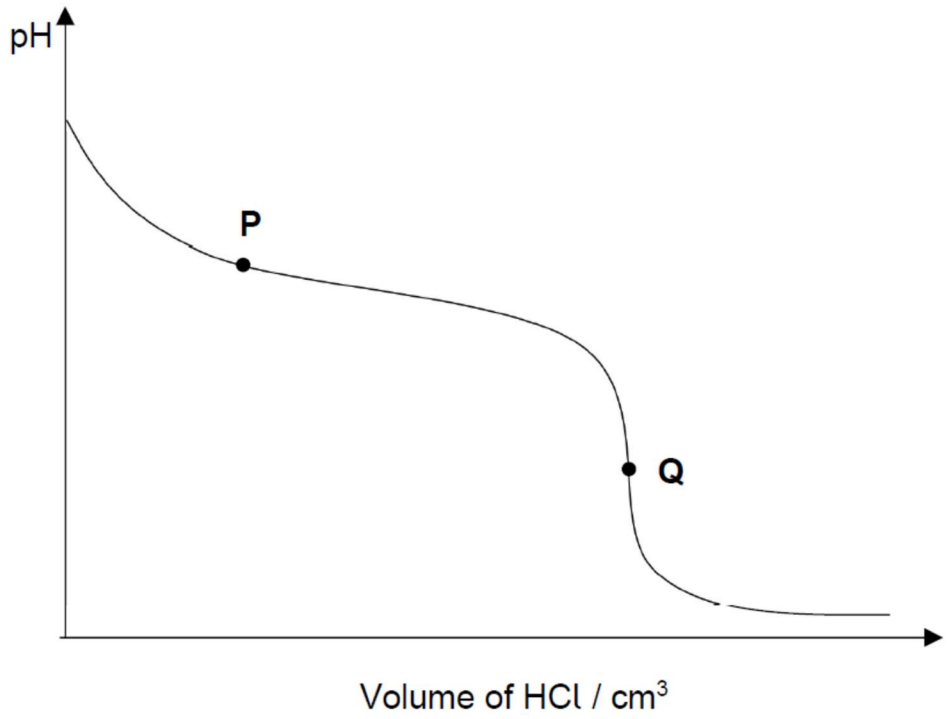
(b) A 20 cm^3 of 0.25 mol dm^{-3} ethylamine solution was titrated against a 0.30 mol dm^{-3} aqueous hydrochloric acid. The pH curve for the reaction is as shown.



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(Question 5 continued)

(b) **(i)** Formulate an equation for the reaction between ethylamine and hydrochloric acid. [1]

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(ii) Identify the major species at these points. [2]

P:

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Q:

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(This question continues on the following page)

(Question 5 continued)

(b) (iii) Determine the pH at the equivalence point, to two decimal places using section 1 and 21 of the data booklet. [4]

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(iv) The buffer solution is formed when hydrochloric acid is added to ethylamine solution at the appropriate volumes. Determine the volume where the maximum buffer capacity occurs. [2]

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(Question 5 continued)

(c) A student repeated the experiment in **(b)** using phenolphthalein instead of a pH probe. [2]

Predict, giving a reason, if the volume of endpoint obtained from the titration would be different from that obtained using a pH probe.

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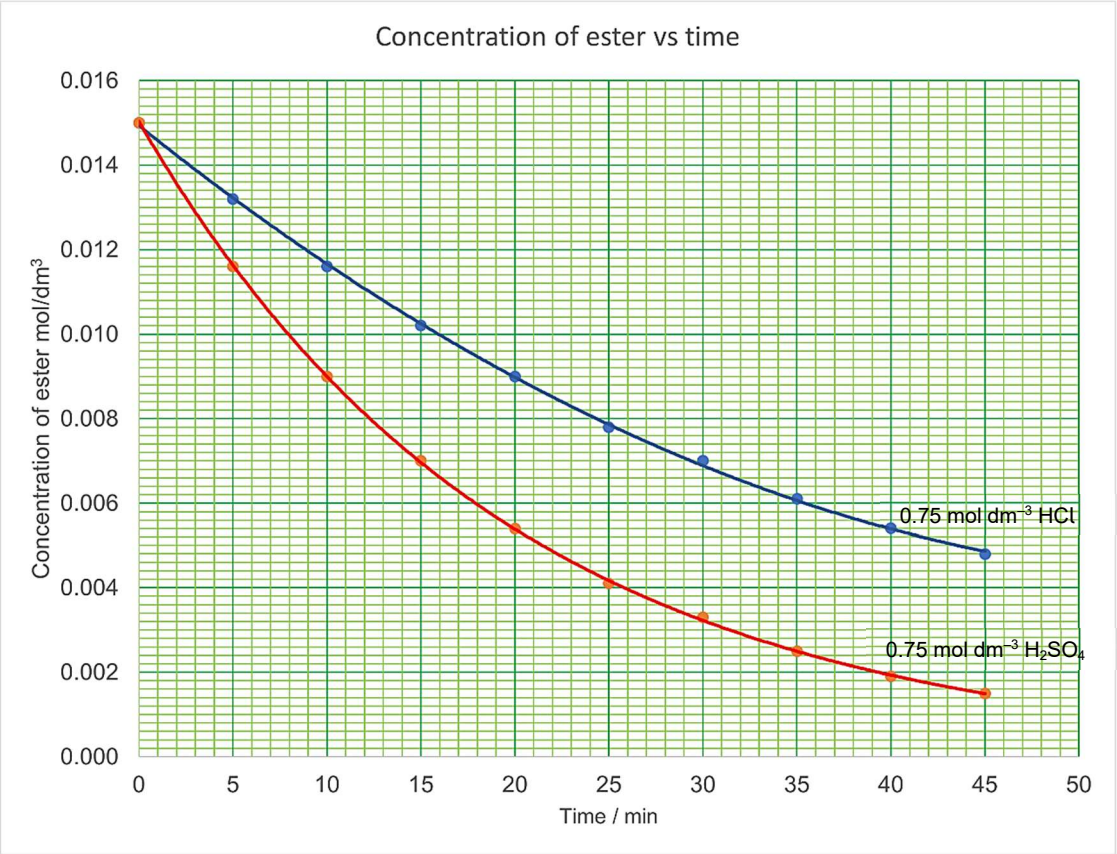
6. The rate equation for the hydrolysis of esters was determined by a series of experiments. The hydrolysis of 0.015 mol dm^{-3} ethyl 2–methyl butanoate was carried out at 355 K, using 0.75 mol dm^{-3} hydrochloric acid. The experiment was repeated using 0.75 mol dm^{-3} sulfuric acid at 355 K. The following graphs were obtained.



(a) Using the graphs above, deduce the order of reaction with respect to H^+ and ethyl 2-methyl butanoate. Hence, write the rate equation of the hydrolysis of the ester, ethyl 2-methyl butanoate. [3]

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(This question continues on the following page)

(Question 6 continued)

(b) The hydrolysis of 0.015 mol dm^{-3} of ethyl 2–methyl butanoate was repeated at 500K, using 0.75 mol dm^{-3} hydrochloric acid. Given that the initial rate of the hydrolysis at 500K was 4.67 x 10^{-3} mol dm^{-3} min^{-1}, calculate the rate constant for the hydrolysis of ethyl 2-methyl butanoate at 500K and state its units. [2]

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(c) In the absence of a catalyst, the hydrolysis of ethyl 2-methyl butanoate is very slow. Sketch and label a suitable Maxwell Boltzmann distribution curve to show how the rate will change if the catalyst is removed. [2]

(This question continues on the following page)

(Question 6 continued)

(d) Using the data and sections 1 and 2 of the data booklet, calculate the activation energy in kJ mol^{-1}, for the hydrolysis of ethyl 2-methyl butanoate at 400K and 300K without a catalyst. [2]

Temperature	Rate Constant, *k*
300K	0.12
400K	0.20

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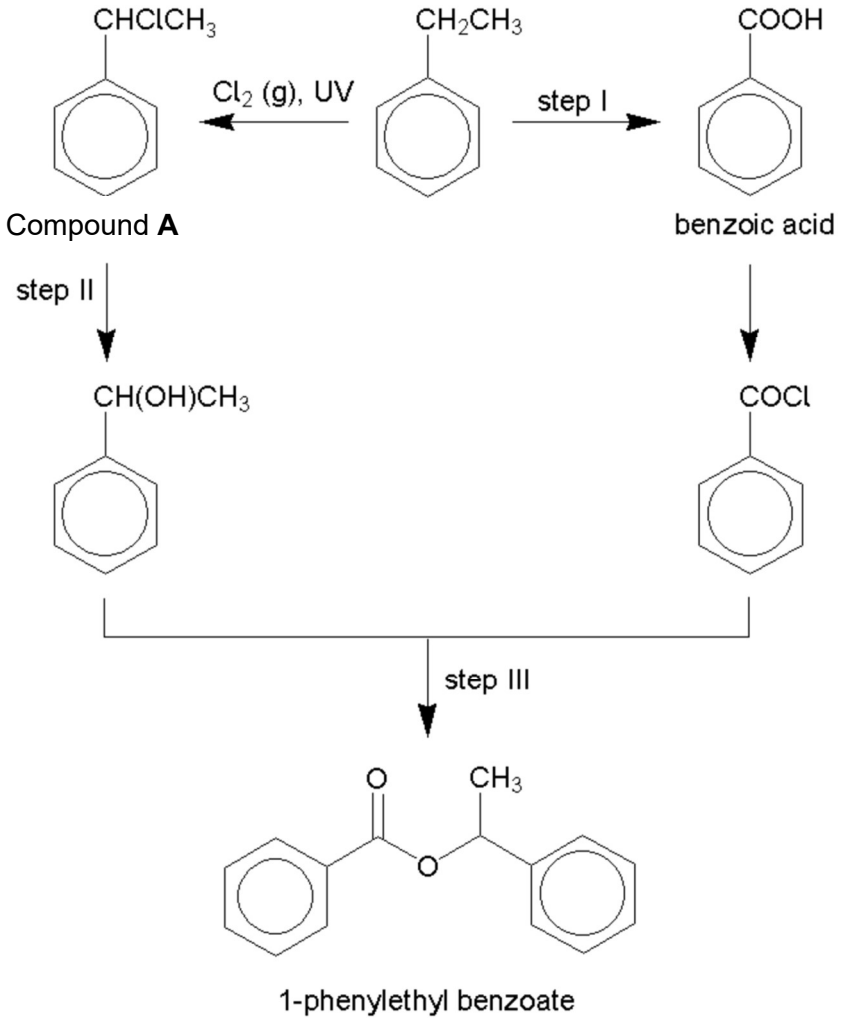
7. **(a)** 1-phenylethyl benzoate is an ester that is used in numerous cosmetic products and can be made from ethylbenzene by the following reaction scheme.



(i) Compound **A** shows optical activity. Draw the three-dimensional representations of the two enantiomers. [1]

(This question continues on the following page)

(Question 7 continued)

(a) **(ii)** Ethylbenzene undergoes oxidation in step I to form benzoic acid and carbon dioxide as the only carbon-containing products. [1]

Formulate a balanced equation for the oxidation of ethylbenzene using [O].

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(iii) An optically pure sample of **A** is reacted in step II and the organic product is found to be optically inactive. [2]

State the mechanism that occurs, and the reagents and conditions required.

Type of reaction:

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Reagents and conditions:

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(This question continues on the following page)

(Question 7 continued)

(a) **(iv)** Explain the mechanism of the reaction in step II using curly arrows to represent the movement of electron pairs. [3]

(v) Explain why the organic product in step II is optically inactive. [2]

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(vi) Identify the inorganic by-product in step III. [1]

Inorganic by-product:

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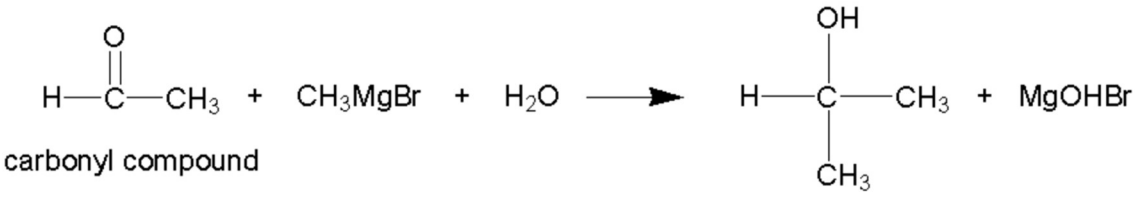
(This question continues on the following page)

(Question 7 continued)

(b) Halogenoalkanes, such as bromomethane, tends to attract nucleophiles due to its electron deficient carbon. When bromomethane is reacted with magnesium in ether, it forms an organomagnesium compound, as shown.

$$CH_3{-}Br + Mg \rightarrow CH_3{-}MgBr$$

The organomagnesium compound instead undergoes reaction with electrophiles. One such reaction is with carbonyl compound:



(i) Explain why the organomagnesium compound undergoes reaction with electrophile instead of nucleophile. [1]

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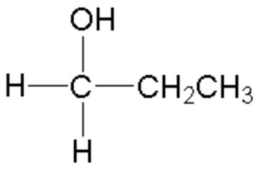
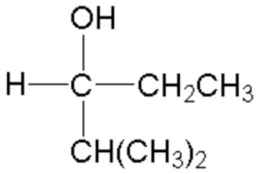
(Question 7 continued)

(b) **(ii)** Compound **C** can be synthesised in two steps from compound **B** with the use of an organomagnesium compound in one of the steps. [3]



compound **B**



compound **C**

Suggest the synthetic route including all the necessary reactants and steps.

(iii) State the name of compound **C**, applying International Union of Pure and Applied Chemistry (IUPAC) rules. [1]

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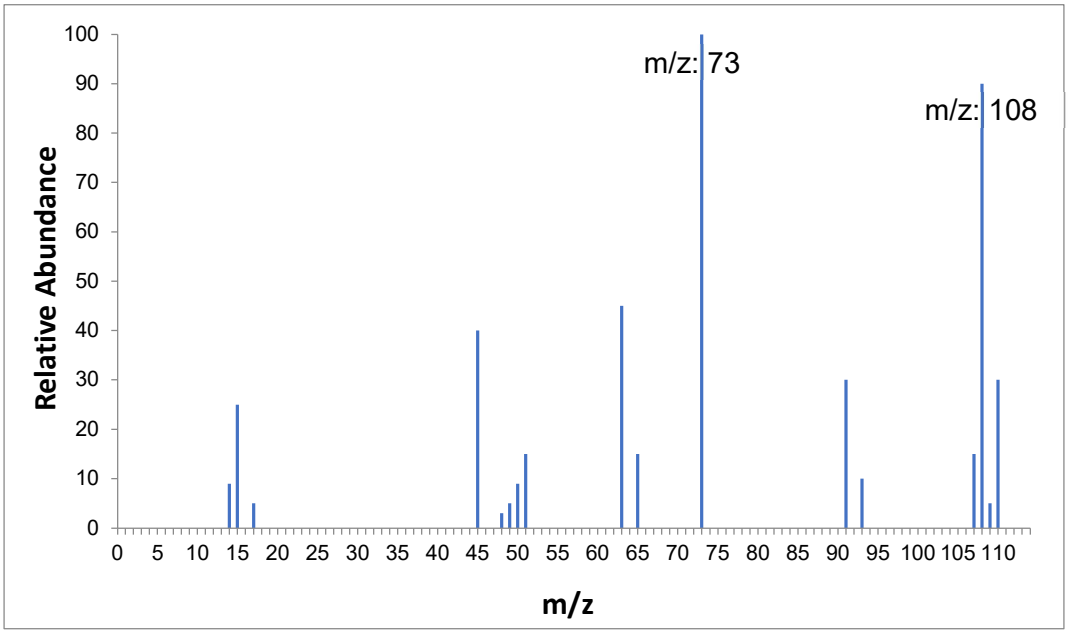
8. A student performed a reaction to synthesize 3-chloropropanoic acid.

(a) After the isolation of the organic products from the reaction, the student analyzed a sample of 3-chloropropanoic acid using mass spectroscopy and obtained the following mass spectrum.



Suggest the formula of the species for the peaks at the following m/z values. [2]

73: .....

108: .....

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(Question 8 continued)

(b) Upon the separation and isolation of the two isomers of 3-chloropropanoic acid, the student used Infrared red (IR) spectroscopy to analyze the samples. Explain why the molecule absorbs infrared radiation whereas some molecules do not. [1]

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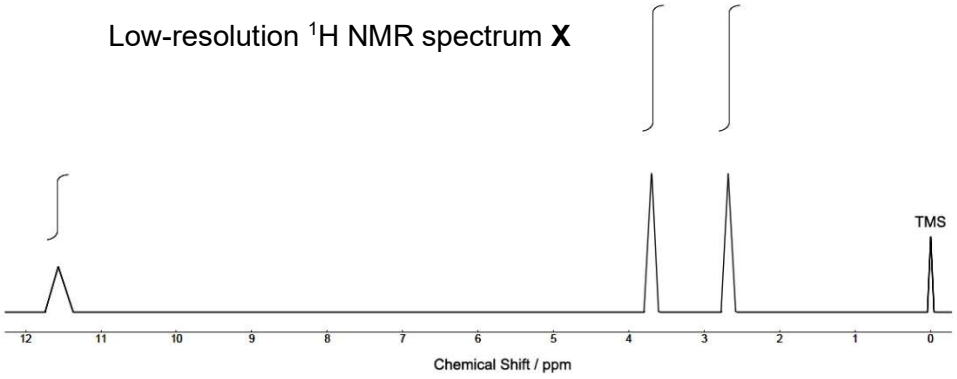
(c) The low-resolution ^{1}H NMR spectra were obtained for 2-chloropropanoic acid, $CH_3CHClCOOH$, and 3-chloropropanoic acid, CH_2ClCH_2COOH:

Low-resolution ^{1}H NMR spectrum **X**



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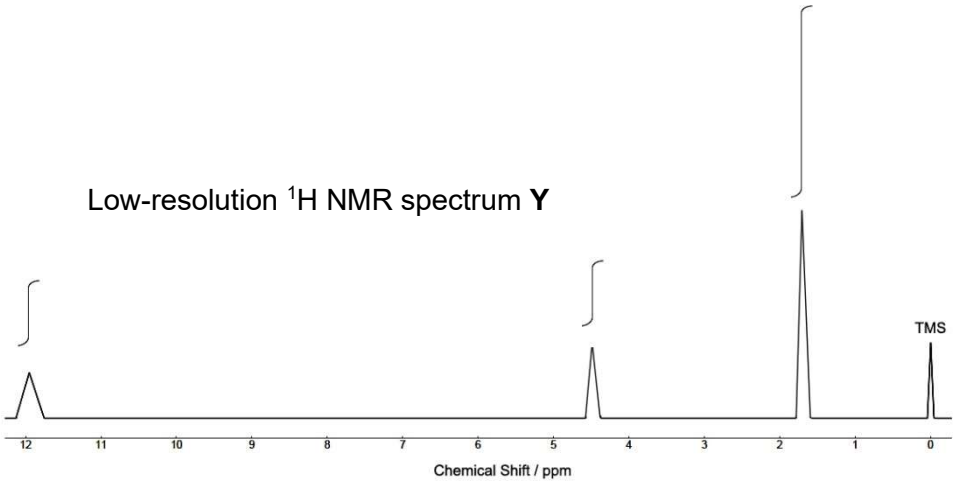
(Question 8 continued)

(c)

Low-resolution ^{1}H NMR spectrum **Y**



(i) Using the information on the 1H NMR spectrum, identify the 1H NMR spectrum for 2-chloropropanoic acid and 3-chloropropanoic acid and state a reason for your answer. [2]

2-chloropropanoic: ^{1}H NMR spectrum .....

3-chloropropanoic: ^{1}H NMR spectrum .....

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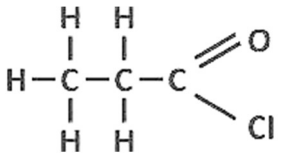
(This question continues on the following page)

(Question 8 continued)

(c) (ii) Deduce the splitting pattern of the peaks in another isomer, propanoyl chloride, CH_3CH_2COCl in high-resolution ^1H NMR spectrum. [2]



A B

Splitting pattern of A: .....

Splitting pattern of B: .....

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