Diploma Programme
Programme du diplôme
Programa del Diploma

Chemistry
Higher level
Paper 2

Friday 14 May 2021 (morning)

2 hours 15 minutes

Candidate session number

Instructions to candidates

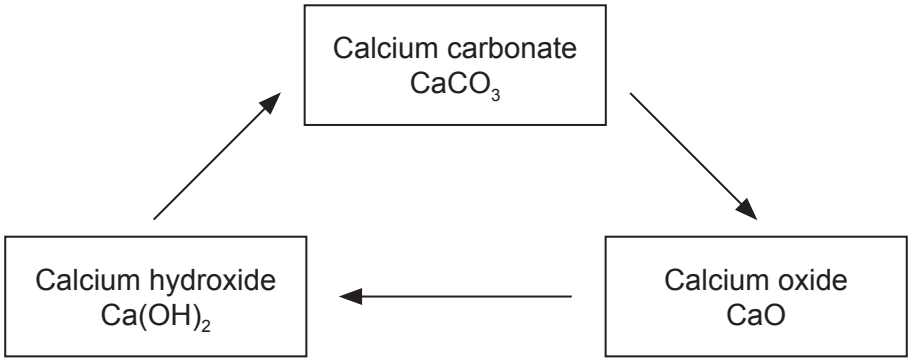
- Write your session number in the boxes above.
- Do not open this examination paper until instructed to do so.
- Answer all questions.
- Answers must be written within the answer boxes provided.
- A calculator is required for this paper.
- A clean copy of the **chemistry data booklet** is required for this paper.
- The maximum mark for this examination paper is **[90 marks]**.

2221 – 6114

21 pages

Answer **all** questions. Answers must be written within the answer boxes provided.

1. Limestone can be converted into a variety of useful commercial products through the lime cycle. Limestone contains high percentages of calcium carbonate, $CaCO_3$.



(a) Calcium carbonate is heated to produce calcium oxide, CaO.

$$CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$$

Calculate the volume of carbon dioxide produced at STP when 555 g of calcium carbonate decomposes. Use sections 2 and 6 of the data booklet. [2]

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(Question 1 continued)

(b) Thermodynamic data for the decomposition of calcium carbonate is given.

Substance	$\Delta H_f^{\ominus}$ / kJ mol^{-1}	$S^{\ominus}$ / J K^{-1} mol^{-1}
$CaCO_3(s)$	−1207	93
$CaO(s)$	−635	40
$CO_2(g)$	−393.5	214

(i) Calculate the enthalpy change of reaction, ΔH, in kJ, for the decomposition of calcium carbonate. [2]

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(ii) Calculate the change in entropy, ΔS, in J K^{-1}, for the decomposition of calcium carbonate. [1]

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(iii) Determine the temperature, in K, at which the decomposition of calcium carbonate becomes spontaneous, using b(i), b(ii) and section 1 of the data booklet.

(If you do not have answers for b(i) and b(ii), use $\Delta H = 190$ kJ and $\Delta S = 180$ J K^{-1}, but these are not the correct answers.) [2]

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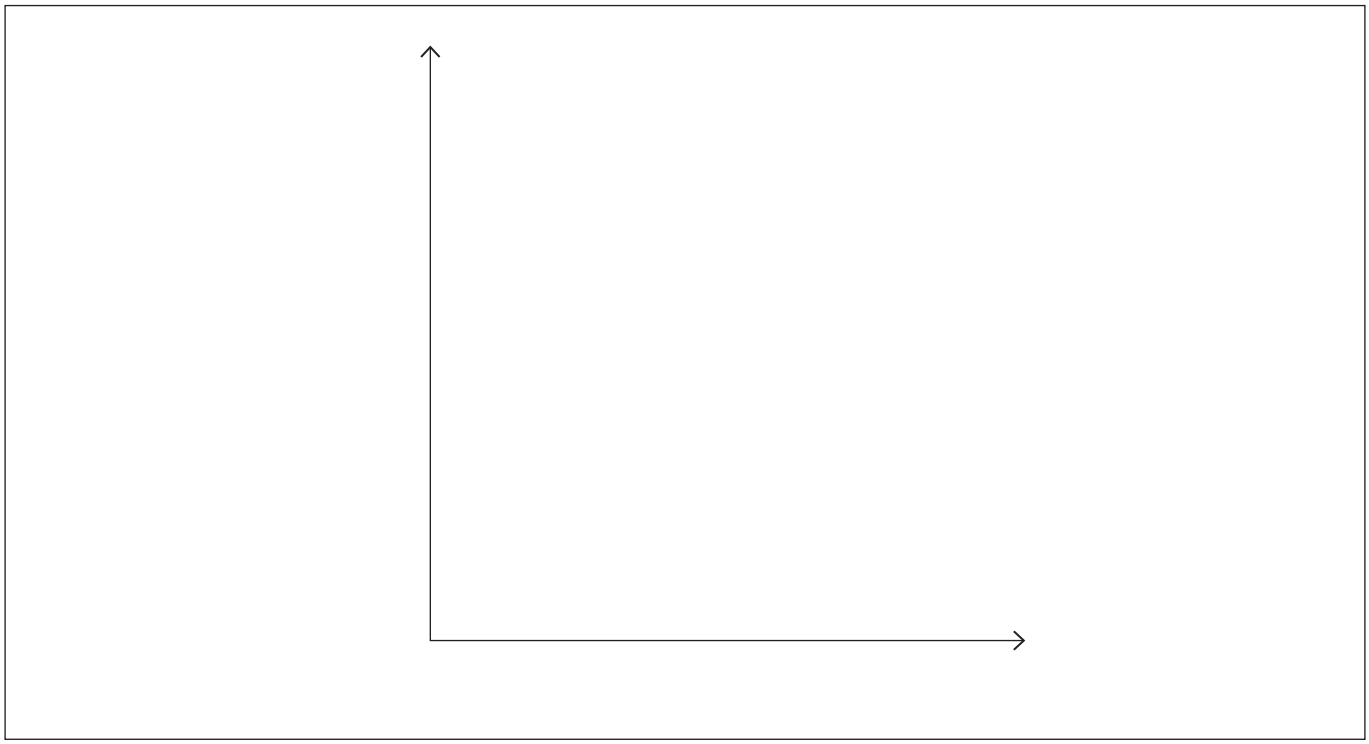
(Question 1 continued)

(iv) Sketch an energy profile for the decomposition of calcium carbonate based on your answer to b(i), labelling the axes and activation energy, E_a. [3]



(v) State how adding a catalyst to the reaction would impact the enthalpy change of reaction, ΔH, and the activation energy, E_a. [1]

ΔH:

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E_a:

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(c) The second step of the lime cycle produces calcium hydroxide, $Ca(OH)_2$.

(i) Write the equation for the reaction of $Ca(OH)_2(aq)$ with hydrochloric acid, $HCl(aq)$. [1]

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(This question continues on the following page)

(Question 1 continued)

(ii) Determine the volume, in dm^3, of $0.015\,mol\,dm^{-3}$ calcium hydroxide solution needed to neutralize $35.0\,cm^3$ of $0.025\,mol\,dm^{-3}$ HCl (aq). [2]

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(iii) Saturated calcium hydroxide solution is used to test for carbon dioxide. Calculate the pH of a $2.33 \times 10^{-2}\,mol\,dm^{-3}$ solution of calcium hydroxide, a strong base. [2]

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(d) Calcium hydroxide reacts with carbon dioxide to reform calcium carbonate.

$$Ca(OH)_2(aq) + CO_2(g) \rightarrow CaCO_3(s) + H_2O(l)$$

(i) Determine the mass, in g, of $CaCO_3$ (s) produced by reacting $2.41\,dm^3$ of $2.33 \times 10^{-2}\,mol\,dm^{-3}$ of $Ca(OH)_2$ (aq) with $0.750\,dm^3$ of CO_2 (g) at STP. [2]

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(Question 1 continued)

(ii) 2.85 g of $CaCO_3$ was collected in the experiment in d(i). Calculate the percentage yield of $CaCO_3$.

(If you did not obtain an answer to d(i), use 4.00 g, but this is not the correct value.) [1]

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(e) Outline how **one** calcium compound in the lime cycle can reduce a problem caused by acid deposition. [1]

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2. The properties of elements can be predicted from their position in the periodic table.

(a) (i) Explain why Si has a smaller atomic radius than Al. [2]

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(ii) Explain why the first ionization energy of sulfur is lower than that of phosphorus. [2]

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(Question 2 continued)

(b) (i) State the condensed electron configurations for Cr and Cr^{3+}. [2]

Cr:

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Cr^{3+}:

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(ii) Describe metallic bonding and how it contributes to electrical conductivity. [3]

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(iii) Deduce, giving a reason, which complex ion $[Cr(CN)_6]^{3-}$ or $[Cr(OH)_6]^{3-}$ absorbs higher energy light. Use section 15 of the data booklet. [1]

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(iv) $[Cr(OH)_6]^{3-}$ forms a green solution. Estimate a wavelength of light absorbed by this complex, using section 17 of the data booklet. [1]

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will not be marked.

(Question 2 continued)

(c) Deduce the Lewis (electron dot) structure and molecular geometry of sulfur tetrafluoride, SF_4, and sulfur dichloride,SCl_2. [4]

Species	**SF_4**	**SCl_2**
Lewis structure		
Molecular geometry	. . . . .	. . . . .

(d) Suggest, giving reasons, the relative volatilities of SCl_2 and H_2O. [3]

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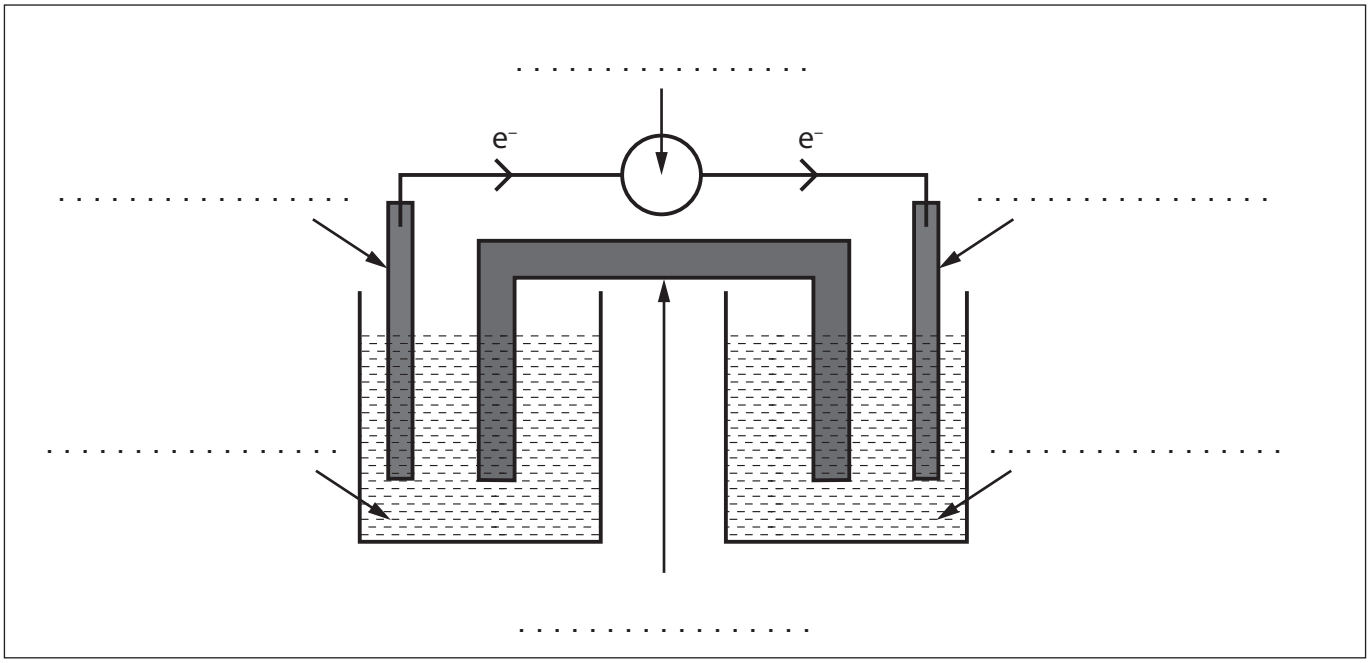
3. Oxidation and reduction reactions can have a variety of commercial uses.

(a) A student decides to build a voltaic cell consisting of an aluminium electrode, Al(s), a tin electrode, Sn(s), and solutions of aluminium nitrate, $Al(NO_3)_3(aq)$ and tin(II) nitrate, $Sn(NO_3)_2(aq)$.

Electron flow is represented on the diagram.

Label each line in the diagram using section 25 of the data booklet. [3]



(b) Write the equation for the expected overall chemical reaction in (a). [1]

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(c) Calculate the cell potential using section 24 of the data booklet. [1]

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(Question 3 continued)

(d) Calculate the Gibbs free energy change, $\Delta G^{\ominus}$, in kJ, for the cell, using section 1 of the data booklet. [2]

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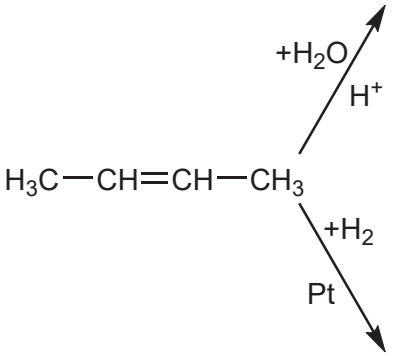
4. Organic chemistry can be used to synthesize a variety of products.

(a) Several compounds can be synthesized from but-2-ene. Draw the structure of the final product for each of the following chemical reactions. [2]



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(b) Determine the change in enthalpy, ΔH, for the combustion of but-2-ene, using section 11 of the data booklet. [3]

$$CH_3CH{=}CHCH_3(g) + 6O_2(g) \rightarrow 4CO_2(g) + 4H_2O(g)$$

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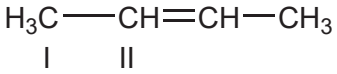
(Question 4 continued)

(c) State the hybridization of the carbon I and II atoms in but-2-ene. [1]



Carbon	**I**	**II**
Hybridization	. . . . .	. . . . .

(d) Draw diagrams to show how sigma (σ) and pi (π) bonds are formed between atoms. [2]

Sigma (σ):

Pi (π):

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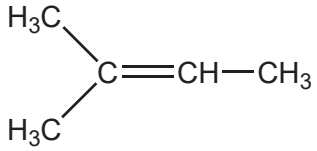
(Question 4 continued)

(e) Sketch the mechanism for the reaction of 2-methylbut-2-ene with hydrogen bromide using curly arrows. [3]



(f) Explain why the major organic product is 2-bromo-2-methylbutane and not 2-bromo-3-methylbutane. [2]

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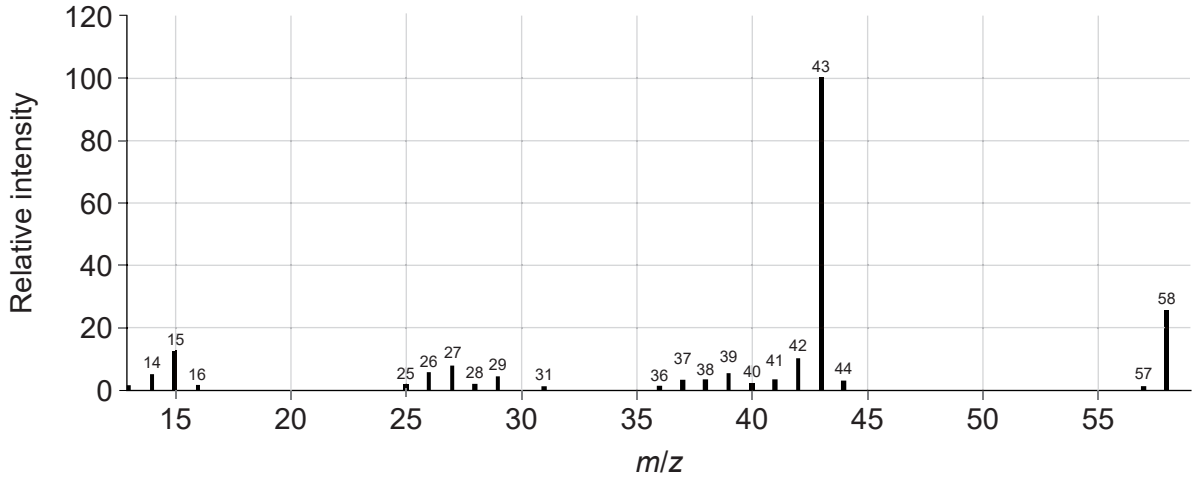
(Question 4 continued)

(g) Combustion analysis of an unknown organic compound indicated that it contained only carbon, hydrogen and oxygen.

(i) Deduce two features of this molecule that can be obtained from the mass spectrum. Use section 28 of the data booklet. [2]



m/*z* 58:

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m/*z* 43:

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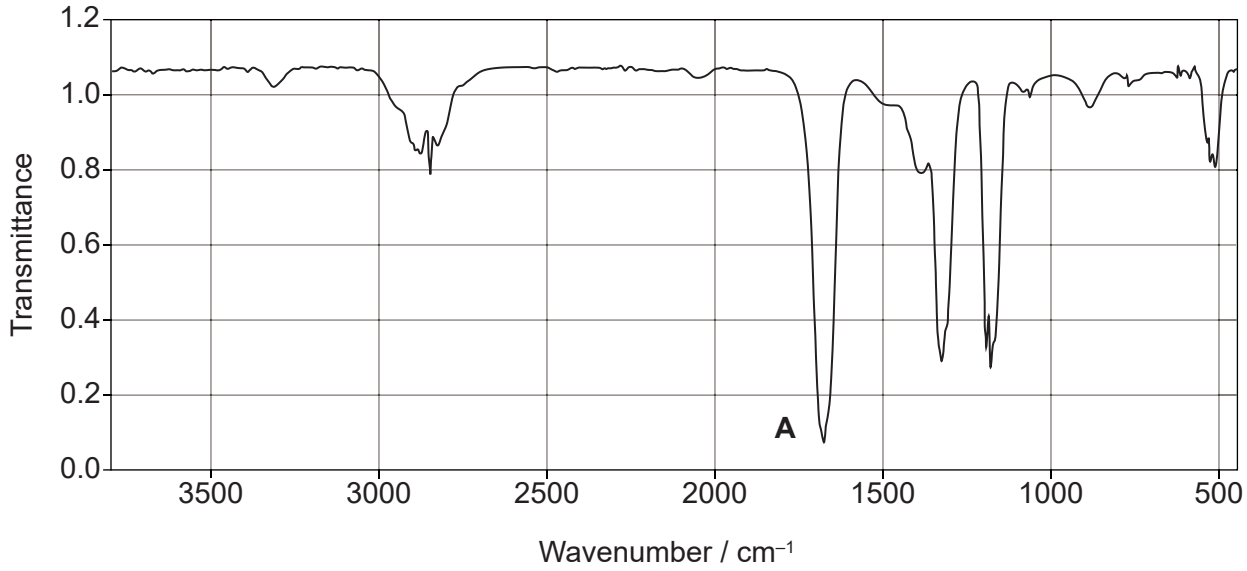
(Question 4 continued)

(ii) Identify the bond responsible for the absorption at **A** in the infrared spectrum. Use section 26 of the data booklet. [1]



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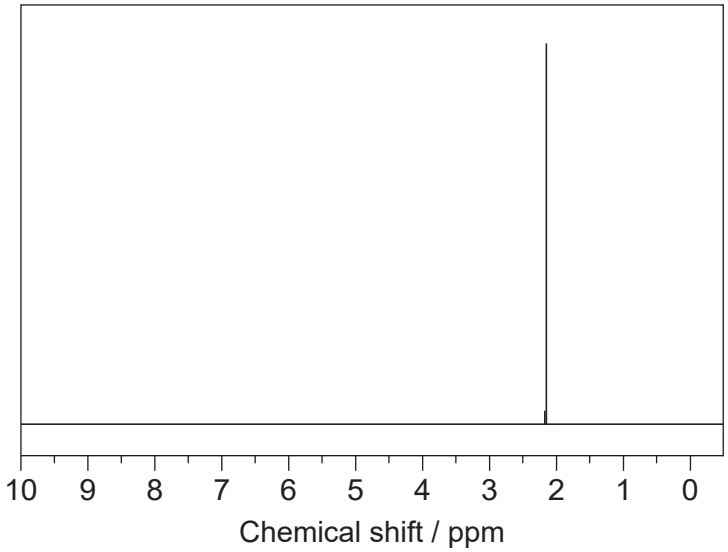
(Question 4 continued)

(iii) Deduce the identity of the unknown compound using the previous information, the ^{1}H NMR spectrum and section 27 of the data booklet. [2]

^{1}H NMR spectrum



Information deduced from ^{1}H NMR:

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Compound:

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(h) (i) Draw the stereoisomers of butan-2-ol using wedge-dash type representations. [1]

(This question continues on the following page)

(Question 4 continued)

(ii) Outline how two enantiomers can be distinguished using a polarimeter. [2]

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5. Ethanol and methanoic acid are important industrial products.

(a) Ethanol is used as a fuel.

(i) Write the chemical equation for the complete combustion of ethanol. [1]

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(ii) Deduce the change in enthalpy, ΔH, in kJ, when 56.00 g of ethanol is burned. Use section 13 in the data booklet. [2]

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(b) Oxidation of ethanol with potassium dichromate, $K_2Cr_2O_7$, can form two different organic products. Determine the names of the organic products and the methods used to isolate them. [2]

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(Question 5 continued)

(c) Write the equation and name the organic product when ethanol reacts with methanoic acid. [2]

Equation:

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Product name:

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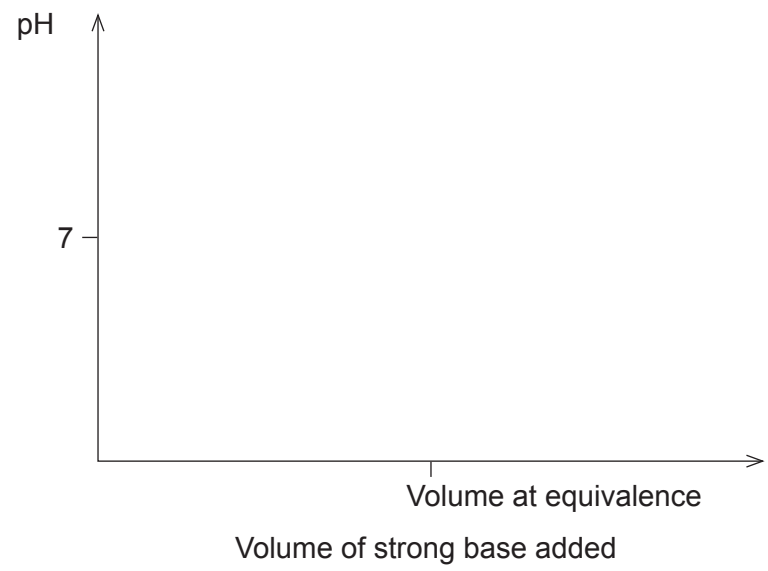
(d) (i) Sketch the titration curve of methanoic acid with sodium hydroxide, showing how you would determine methanoic acid pK_a. [2]



(ii) Identify an indicator that could be used for the titration in 5(d)(i), using section 22 of the data booklet. [1]

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(Question 5 continued)

(e) Determine the concentration of methanoic acid in a solution of pH = 4.12. Use section 21 of the data booklet. [2]

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(f) Identify if aqueous solutions of the following salts are acidic, basic, or neutral. [2]

Sodium methanoate:

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Ammonium chloride:

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Sodium nitrate:

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6. Bromate and bromide ions react in acidic aqueous solution.

$$BrO_3^-(aq) + 5Br^-(aq) + 6H^+(aq) \rightarrow 3Br_2(l) + 3H_2O(l)$$

The following rate data was collected.

Experiment	**$[BrO_3^-]$ / mol dm^{-3}**	**$[Br^-]$ / mol dm^{-3}**	**$[H^+]$ / mol dm^{-3}**	**Initial rate / mol dm^{-3} s^{-1}**
1	0.10	0.10	0.10	8.0×10^{-4}
2	0.20	0.10	0.10	1.6×10^{-3}
3	0.20	0.20	0.10	3.2×10^{-3}
4	0.10	0.10	0.20	3.2×10^{-3}

(a) Determine the rate expression for the reaction. [2]

Order of reaction with respect to BrO_3^-:

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Order of reaction with respect to Br^-:

. . . . . .

Order of reaction with respect to H^+:

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Rate expression:

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(b) Determine the value and unit of the rate constant using the rate expression in (a). [2]

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7. Consider the following equilibrium reaction:

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

(a) State the equilibrium constant expression, K_c, for the reaction above. [1]

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(b) State and explain how the equilibrium would be affected by increasing the volume of the reaction container at a constant temperature. [3]

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(c) $SO_2(g)$, $O_2(g)$ and $SO_3(g)$ are mixed and allowed to reach equilibrium at 600 °C.

	SO_2	**O_2**	**SO_3**
Initial concentration / mol dm^{-3}	2.00	1.50	3.00
Equilibrium concentration / mol dm^{-3}	1.50		

Determine the value of K_c at 600 °C. [2]

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References:

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4.(g)(ii) NIST Mass Spectrometry Data Center Collection © 2014 copyright by the U.S. Secretary of Commerce on behalf of the United States of America. All rights reserved.

4.(g)(iii) SDBS, National Institute of Advanced Industrial Science and Technology (AIST).

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