N12/4/CHEMI/HP2/ENG/TZ0/XX

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CHEMISTRY
HIGHER LEVEL
PAPER 2

Candidate session number

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Friday 9 November 2012 (afternoon)

2 hours 15 minutes

Examination code

8	8	1	2	–	6	1	0	2

INSTRUCTIONS TO CANDIDATES

- Write your session number in the boxes above.
- Do not open this examination paper until instructed to do so.
- Section A: answer all questions.
- Section B: answer two questions.
- Write your answers in the 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]*.

0132

SECTION A

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

1. Two groups of students (Group A and Group B) carried out a project* on the chemistry of some group 7 elements (the halogens) and their compounds.

(a) In the first part of the project, the two groups had a sample of iodine monochloride (a corrosive brown liquid) prepared for them by their teacher using the following reaction.

$$I_2(s) + Cl_2(g) \rightarrow 2ICl(l)$$

The following data were recorded.

Mass of $I_2(s)$	10.00 g
Mass of $Cl_2(g)$	2.24 g
Mass of ICl(l) obtained	8.60 g

(i) State the number of significant figures for the masses of $I_2(s)$ and ICl(l). *[1]*

$I_2(s)$: . . . .

ICl(l): . . . .

(ii) The iodine used in the reaction was in excess. Determine the theoretical yield, in g, of ICl(l). *[3]*

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(This question continues on the following page)

* Adapted from J Derek Woollins, (2009), *Inorganic Experiments* and Open University, (2008), *Exploring the Molecular World*.

(Question 1 continued)

(iii) Calculate the percentage yield of ICl(l). *[1]*

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(iv) Using a digital thermometer, the students discovered that the reaction was exothermic. State the sign of the enthalpy change of the reaction, ΔH. *[1]*

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(b) Although the molar masses of ICl and Br_2 are very similar, the boiling point of ICl is 97.4 °C and that of Br_2 is 58.8 °C. Explain the difference in these boiling points in terms of the intermolecular forces present in each liquid. *[2]*

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(Question 1 continued)

(c) The students reacted ICl(l) with CsBr(s) to form a yellow solid, $CsICl_2$(s), as one of the products. $CsICl_2$(s) has been found to produce very pure CsCl(s) which is used in cancer treatment.

To confirm the composition of the yellow solid, Group A determined the amount of iodine in 0.2015 g of $CsICl_2$(s) by titrating it with 0.0500 mol dm^{-3} $Na_2S_2O_3$(aq). The following data were recorded for the titration.

Mass of $CsICl_2$(s) taken (in g ± 0.0001)	0.2015
Initial burette reading of 0.0500 mol dm^{-3} $Na_2S_2O_3$(aq) (in cm^3 ± 0.05)	1.05
Final burette reading of 0.0500 mol dm^{-3} $Na_2S_2O_3$(aq) (in cm^3 ± 0.05)	25.25

(i) Calculate the percentage of iodine by mass in $CsICl_2$(s), correct to **three** significant figures. *[1]*

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(ii) State the volume, in cm^3, of 0.0500 mol dm^{-3} $Na_2S_2O_3$(aq) used in the titration. *[1]*

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(This question continues on the following page)

(Question 1 continued)

(iii) Determine the amount, in mol, of 0.0500 mol dm^{-3} $Na_2S_2O_3$ (aq) added in the titration. *[1]*

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(iv) The overall reaction taking place during the titration is:

$$CsICl_2(s) + 2Na_2S_2O_3(aq) \rightarrow NaCl(aq) + Na_2S_4O_6(aq) + CsCl(aq) + NaI(aq)$$

Calculate the amount, in mol, of iodine atoms, I, present in the sample of $CsICl_2$ (s). *[1]*

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(v) Calculate the mass of iodine, in g, present in the sample of $CsICl_2$ (s). *[1]*

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(vi) Determine the percentage by mass of iodine in the sample of $CsICl_2$ (s), correct to **three** significant figures, using your answer from (v). *[1]*

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(This question continues on the following page)

(Question 1 continued)

(d) Group B heated the yellow solid, $CsICl_2(s)$, which turned white and released a brown gas which condensed into a brown liquid.

Group B identified the white solid as $CsCl(s)$. Suggest the identity of the brown liquid. *[1]*

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(e) When iodine reacts with excess chlorine, ICl_3 can form. Deduce the Lewis (electron dot) structure of ICl_3 and ICl_2^- and state the name of the shape of each species. *[4]*

	ICl_3	**ICl_2^-**
Lewis structure		
Name of shape		

(This question continues on the following page)

(Question 1 continued)

(f) In this project the students explored several aspects of the chemistry of the halogens. In the original preparation of ICl(l), they observed the yellow-green colour of chlorine gas, $Cl_2(g)$, reacting with solid iodine, $I_2(s)$.

(i) State the **full** electron configuration of iodine ($Z = 53$). *[1]*

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(ii) Chlorine can also react with water. State the balanced chemical equation for the reaction of $Cl_2(g)$ with water. *[1]*

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(iii) One important use of chlorine is in the synthesis of poly(chloroethene), PVC. Identify the monomer used to make PVC and state **one** of the uses of PVC. *[2]*

Monomer:

. . . .

Use:

. . . .

2. Lithium and boron are elements in period 2 of the periodic table. Lithium occurs in group 1 (the alkali metals) and boron occurs in group 3. Isotopes exist for both elements.

(a) (i) Distinguish between the terms *group* and *period*. *[1]*

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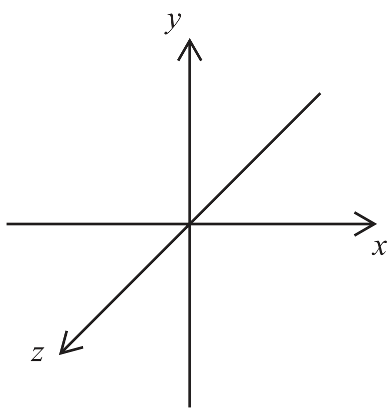
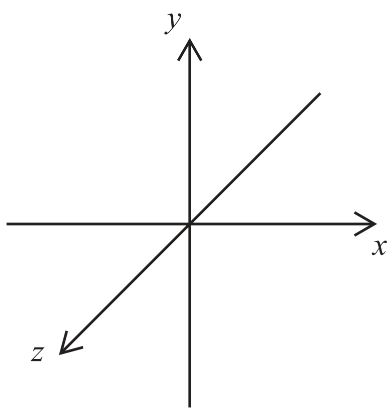
(ii) Lithium exists as two isotopes with mass numbers of 6 and 7. Deduce the number of protons, electrons and neutrons for each isotope. *[2]*

Mass number (A)	**Number of protons**	**Number of electrons**	**Number of neutrons**
6			
7			

(iii) The electron configuration of boron is $1s^2 2s^2 2p^1$. Draw the shape of an s orbital and a p_x orbital on the axes below. *[1]*



s orbital



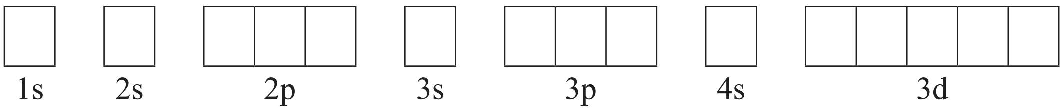
p_x orbital

(This question continues on the following page)

(Question 2 continued)

(b) (i) Explain why metals are good conductors of electricity and why they are malleable. *[2]*

(ii) Cobalt is a transition metal. One common ion of cobalt is Co^{3+}. Draw the orbital diagram (using the arrow-in-box notation) for the Co^{3+} ion. *[1]*



(iii) State the other most common ion of cobalt. *[1]*

(iv) Explain why the complex $[Co(NH_3)_6]Cl_3$ is coloured. *[3]*

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Answers written on this page will not be marked.

3. Buffer solutions are widely used in both chemical and biochemical systems.

(a) Describe the composition of an acidic buffer solution. *[1]*

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(b) Determine the pH of a buffer solution, correct to **two** decimal places, showing your working, consisting of 10.0 g of CH_3COOH and 10.0 g of CH_3COONa in 0.250 dm^3 of solution. K_a for $CH_3COOH = 1.8 \times 10^{-5}$ at 298 K. *[5]*

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SECTION B

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

4. Arsenic and nitrogen play a significant role in environmental chemistry. Arsenous acid, H_3AsO_3, can be found in oxygen-poor (anaerobic) water, and nitrogen-containing fertilizers can contaminate water.

(a) (i) Define *oxidation* and *reduction* in terms of electron loss or gain. *[1]*

Oxidation:

. . . .

Reduction:

. . . .

(ii) Deduce the oxidation numbers of arsenic and nitrogen in each of the following species. *[4]*

As_2O_3: . . . .

NO_3^-: . . . .

H_3AsO_3: . . . .

N_2O_3: . . . .

(iii) Distinguish between the terms *oxidizing agent* and *reducing agent*. *[1]*

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(This question continues on the following page)

(Question 4 continued)

(iv) In the removal of arsenic from contaminated groundwater, H_3AsO_3 is often first oxidized to arsenic acid, H_3AsO_4.

The following **unbalanced** redox reaction shows another method of forming H_3AsO_4.

$$As_2O_3(s) + NO_3^-(aq) \rightarrow H_3AsO_4(aq) + N_2O_3(aq)$$

Deduce the balanced redox equation in **acid**, and then identify both the oxidizing and reducing agents. *[3]*

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(b) The electrolysis of aqueous copper(II) sulfate is an example of an electrolysis process where the nature of the electrodes can determine which products form. Platinum electrodes were used in **process 1** and copper electrodes in **process 2**.

(i) Draw an annotated diagram of the electrolytic cell in **process 1** and identify the direction of electron flow. *[2]*

(This question continues on the following page)

(Question 4 continued)

(ii) For **process 1** (platinum electrodes), state the half-equations occurring at the positive electrode (anode) and negative electrode (cathode). **Include state symbols for all species**. Describe what is observed at each electrode and comment on any change in the colour and the acidity of the solution. *[7]*

Half-equation at positive electrode (anode):

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Half-equation at negative electrode (cathode):

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Observation at positive electrode (anode):

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Observation at negative electrode (cathode):

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Change in colour (if any) of the solution:

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Change in acidity (if any) of the solution:

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(This question continues on the following page)

(Question 4 continued)

(iii) For **process 2** (copper electrodes), state the half-equations occurring at the positive electrode (anode) and negative electrode (cathode). **Include state symbols for all species**. Describe what is observed at each electrode and comment on any change in the colour and the acidity of the solution. *[7]*

Half-equation at positive electrode (anode):

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Half-equation at negative electrode (cathode):

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Observation at positive electrode (anode):

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Observation at negative electrode (cathode):

. . . .

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Change in colour (if any) of the solution:

. . . .

. . . .

Change in acidity (if any) of the solution:

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5. The strength of a covalent bond is measured in terms of its bond enthalpy.

(a) Define the term *average bond enthalpy*. *[2]*

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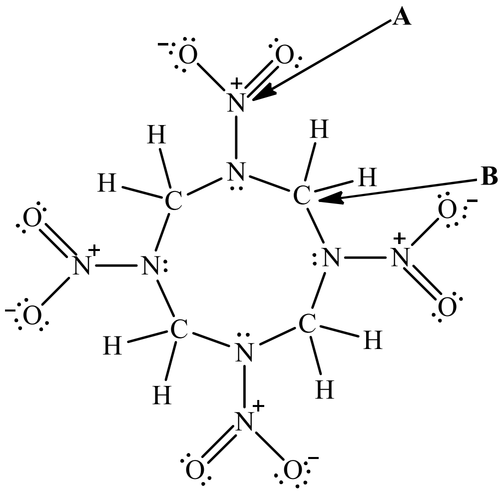
(b) 1,3,5,7-tetranitro-1,3,5,7-tetrazocane, shown below, can be used as an explosive.



The following equation represents the thermal decomposition of the compound.

$$C_4H_8N_8O_8\,(s) \rightarrow 4N_2\,(g) + 4CO\,(g) + 4H_2O\,(g)$$

(This question continues on the following page)

(Question 5 continued)

(i) Calculate the enthalpy change when 10.0 g of the compound decomposes, using average bond enthalpy data from Table 10 of the Data Booklet and the following additional average bond enthalpy data at 298 K. *[4]*

Bond	**ΔH / kJ mol^{-1}**
C≡O	1072
N–O	201
N=O	607

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(ii) The CO molecule has dative covalent bonding. Identify a nitrogen-containing positive ion which also has this type of bonding. *[1]*

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(This question continues on the following page)

(Question 5 continued)

(iii) Describe in words and with the aid of a suitable diagram the difference between sigma (σ) and pi (π) bonds. *[3]*

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(iv) Determine the number of σ and π bonds in 1,3,5,7-tetranitro-1,3,5,7-tetrazocane, using the Lewis structure shown on page 16. *[2]*

σ bonds: . . . .

π bonds: . . . .

(This question continues on the following page)

(Question 5 continued)

(v) Explain the term *hybridization* and deduce the hybridization (sp, sp^2 or sp^3) of the atoms labelled **A** and **B** in the diagram on page 16. *[3]*

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(c) Methanol reacts with carbon monoxide to form ethanoic acid, $CH_3COOH(l)$.

$$CH_3OH(l) + CO(g) \rightarrow CH_3COOH(l)$$

(i) Predict the sign of the entropy change, ΔS, of the system and explain your answer. *[2]*

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(ii) Define the term *standard enthalpy change of formation*, $\Delta H_f^{\ominus}$. *[2]*

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(This question continues on the following page)

(Question 5 continued)

(iii) The standard enthalpy change of formation of CO (g) is –111 kJ mol^{-1}. Using Table 11 of the Data Booklet, determine the enthalpy change of the reaction, in kJ mol^{-1}. *[1]*

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(iv) The standard entropy of CO (g) is 198 J K^{-1} mol^{-1}. Using Table 11 of the Data Booklet, determine the standard entropy change of the reaction, in J K^{-1} mol^{-1}. *[1]*

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(v) Determine the standard free energy change for the reaction at 298 K, in kJ mol^{-1}, using your answers from (iii) and (iv) and state whether the reaction is spontaneous or not. *[2]*

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(vi) In industry, this reaction is carried out at a temperature greater than 298 K. State and explain the effect of increasing the temperature on the value of the equilibrium constant, K_c. *[2]*

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6. Chemical kinetics involves an understanding of how the molecular world changes with time.

(a) (i) Define the term *rate of reaction*. *[1]*

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(ii) Temperature and the addition of a catalyst are two factors that can affect the rate of a reaction. State **two** other factors. *[2]*

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(iii) In the reaction represented below, state **one** method that can be used to measure the rate of the reaction.

$$ClO_3^-(aq) + 5Cl^-(aq) + 6H^+(aq) \rightarrow 3Cl_2(aq) + 3H_2O(l)$$ *[1]*

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(This question continues on the following page)

(Question 6 continued)

(b) A catalyst provides an alternative pathway for a reaction, lowering the activation energy, E_a.

(i) Define the term *activation energy*, E_a. *[1]*

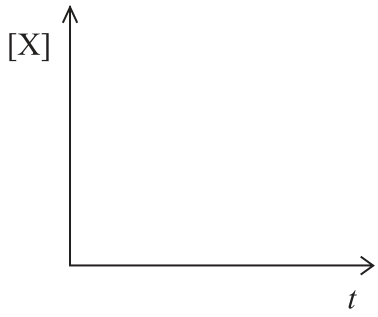
(ii) Sketch the **two** Maxwell–Boltzmann energy distribution curves for a fixed amount of gas at two different temperatures, T_1 and T_2 ($T_2 > T_1$). Label **both** axes. *[3]*

(This question continues on the following page)

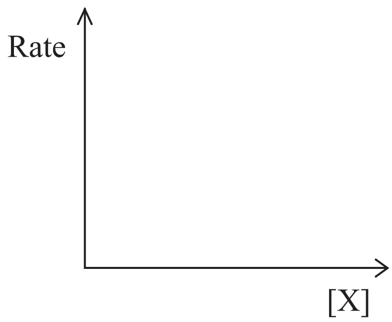
(Question 6 continued)

(c) Sketch graphical representations of the following reactions, for X $\rightarrow$ products.

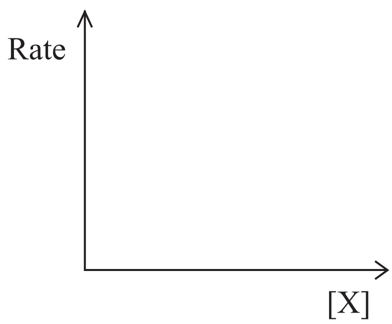
(i) Concentration of reactant X against time for a **zero-order** reaction. *[1]*



(ii) Rate of reaction against concentration of reactant X for a **zero-order** reaction. *[1]*



(iii) Rate of reaction against concentration of reactant X for a **first-order** reaction. *[1]*



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(Question 6 continued)

(d) For the reaction below, consider the following experimental data.

$$2ClO_2(aq) + 2OH^-(aq) \rightarrow ClO_3^-(aq) + ClO_2^-(aq) + H_2O(l)$$

Experiment	**Initial [ClO_2(aq)] / mol dm^{-3}**	**Initial [OH^-(aq)] / mol dm^{-3}**	**Initial rate / mol dm^{-3} s^{-1}**
1	1.00×10^{-1}	1.00×10^{-1}	2.30×10^{-1}
2	5.00×10^{-2}	1.00×10^{-1}	5.75×10^{-2}
3	5.00×10^{-2}	3.00×10^{-2}	1.73×10^{-2}

(i) Deduce the rate expression. *[2]*

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(This question continues on the following page)

(Question 6 continued)

(ii) Determine the rate constant, k, and state its units, using the data from Experiment 2. *[2]*

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(iii) Calculate the rate, in $mol\,dm^{-3}\,s^{-1}$, when $[ClO_2(aq)] = 1.50\times10^{-2}\,mol\,dm^{-3}$ and $[OH^-(aq)] = 2.35\times10^{-2}\,mol\,dm^{-3}$. *[1]*

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(e) Another reaction involving $OH^-(aq)$ is the base hydrolysis reaction of an ester.

$$CH_3COOCH_2CH_3(aq) + OH^-(aq) \rightarrow CH_3COO^-(aq) + CH_3CH_2OH(aq)$$

(i) Apply IUPAC rules to name the ester, $CH_3COOCH_2CH_3(aq)$. *[1]*

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(ii) Describe **qualitatively** the relationship between the rate constant, k, and temperature, T. *[1]*

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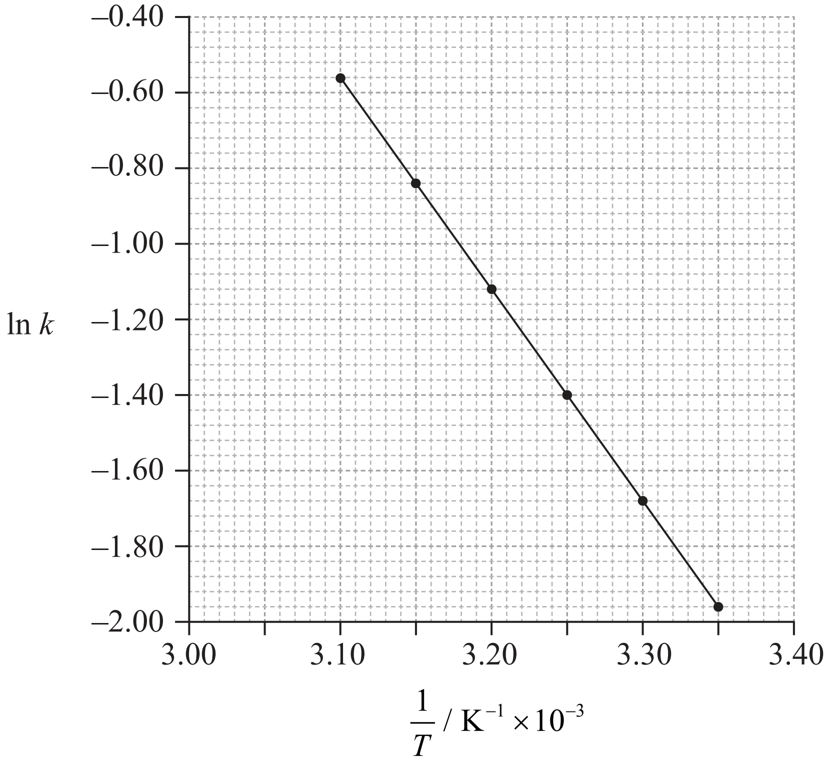
(Question 6 continued)

(iii) The rate of this reaction was measured at different temperatures and the following data were recorded.



Using data from the graph, determine the activation energy, E_a, correct to **three** significant figures and **state its units**. *[4]*

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(This question continues on the following page)

(Question 6 continued)

(f) A two-step mechanism has been proposed for the following reaction.

Step 1: $ClO^-(aq) + ClO^-(aq) \rightarrow ClO_2^-(aq) + Cl^-(aq)$

Step 2: $ClO_2^-(aq) + ClO^-(aq) \rightarrow ClO_3^-(aq) + Cl^-(aq)$

(i) Deduce the overall equation for the reaction. *[1]*

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(ii) Deduce the rate expression for each step. *[2]*

Step 1:

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Step 2:

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7. Alkenes, alcohols and esters are three families of organic compounds with many commercial uses.

(a) (i) State what is meant by the term *stereoisomers*. *[1]*

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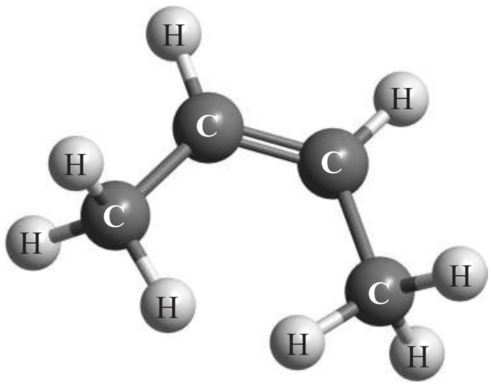
(ii) **X** is an isomer of C_4H_8 and has the structural formula shown below.



Apply IUPAC rules to name this isomer. Deduce the structural formulas of **two** other isomers of C_4H_8. *[3]*

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(iii) State the balanced chemical equation for the reaction of **X** with HBr to form **Y**. *[1]*

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(This question continues on the following page)

(Question 7 continued)

(iv) **Y** reacts with aqueous sodium hydroxide, NaOH(aq), to form an alcohol, **Z**. Identify whether **Z** is a primary, secondary or tertiary alcohol. *[1]*

. . . .

(v) Explain **one** suitable mechanism for the reaction in (iv) using curly arrows to represent the movement of electron pairs. *[4]*

(vi) Deduce the structural formula of the organic product formed when **Z** is oxidized by heating under reflux with acidified potassium dichromate(VI). *[1]*

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(This question continues on the following page)

(Question 7 continued)

(b) An ester which gives apples their characteristic smell contains C, H and O. When 3.00×10^{-3} g of this ester were completely combusted, 6.93×10^{-3} g of CO_2 and 2.83×10^{-3} g of H_2O were produced.

(i) Determine the empirical formula of the ester, showing your working. *[4]*

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(ii) The molar mass of the ester is 116.18 g mol^{-1}. Determine its molecular formula. *[1]*

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(iii) Other than its use in food flavouring, state **one** use of esters. *[1]*

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(This question continues on the following page)

(Question 7 continued)

(c) (i) When 2-bromobutane is refluxed with ethanolic potassium hydroxide (*i.e.* hydroxide ions in ethanol), an elimination reaction occurs in which two different organic products are formed. Explain the mechanism of this reaction, using curly arrows to represent the movement of electron pairs, to show the formation of **one** of the organic products. *[4]*

(ii) Draw the structural formula of the other organic product and draw the structure of an isomer of either product. *[2]*

(This question continues on the following page)

(Question 7 continued)

(iii) 2-bromobutane is optically active. Draw the two enantiomers of 2-bromobutane and compare their physical and chemical properties. *[2]*

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