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CHEMISTRY
HIGHER LEVEL
PAPER 2

Candidate session number

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Monday 7 November 2011 (afternoon)

2 hours 15 minutes

Examination code

8	8	1	1	–	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.

SECTION A

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

1. Airbags are an important safety feature in vehicles. Sodium azide, potassium nitrate and silicon dioxide have been used in one design of airbag.

[Source: www.hilalairbag.net]

Sodium azide, a toxic compound, undergoes the following decomposition reaction under certain conditions.

$$2NaN_3(s) \rightarrow 2Na(s) + 3N_2(g)$$

Two students looked at data in a simulated computer-based experiment to determine the volume of nitrogen generated in an airbag.

(a) Sodium azide involves ionic bonding, and metallic bonding is present in sodium. Describe ionic and metallic bonding. *[2]*

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(Question 1 continued)

(b) Using the simulation programme, the students entered the following data into the computer.

Temperature (T) / °C	**Mass of NaN_3(s) (m) / kg**	**Pressure (p) / atm**
25.00	0.0650	1.08

(i) State the number of significant figures for the temperature, mass and pressure data. *[1]*

T: . . . . . .

m: . . . . . .

p: . . . . . .

(ii) Calculate the amount, in mol, of sodium azide present. *[1]*

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(iii) Determine the volume of nitrogen gas, in dm^3, produced under these conditions based on this reaction. *[4]*

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(Question 1 continued)

(c) The chemistry of the airbag was found to involve three reactions. The first reaction involves the decomposition of sodium azide to form sodium and nitrogen. In the second reaction, potassium nitrate reacts with sodium.

$$2KNO_3(s) + 10Na(s) \rightarrow K_2O(s) + 5Na_2O(s) + N_2(g)$$

(i) Suggest why it is necessary for sodium to be removed by this reaction. *[1]*

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(ii) The metal oxides from the second reaction then react with silicon dioxide to form a silicate in the third reaction.

$$K_2O(s) + Na_2O(s) + SiO_2(s) \rightarrow Na_2K_2SiO_4(s)$$

Draw the structure of silicon dioxide and state the type of bonding present. *[2]*

Structure:

Bonding: . . . . . .

(This question continues on the following page)

(Question 1 continued)

(d) An airbag inflates very quickly.

(i) It takes just 0.0400 seconds to produce nitrogen gas in the simulation. Calculate the average rate of formation of nitrogen in (b) (iii) and state its units. *[1]*

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(ii) The students also discovered that a small increase in temperature (*e.g.* 10 °C) causes a large increase (*e.g.* doubling) in the rate of this reaction. State **one** reason for this. *[1]*

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2. Isotopes are atoms of the same element with different mass numbers. Two isotopes of cobalt are Co-59 and Co-60.

(a) Deduce the missing information and complete the following table. *[2]*

Symbol	$^{59}Co^{3+}$	^{60}Co	
Number of protons	27		53
Number of neutrons		33	72
Number of electrons		27	53

(b) State why the Co-60 radioisotope is used in radiotherapy. *[1]*

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(c) State the **full** electron configuration of $^{59}Co^{3+}$. *[1]*

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

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(b) Deduce the balanced chemical equation for the complete combustion of butan-1-ol. *[1]*

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(c) Determine the standard enthalpy change, in kJ mol^{-1}, for the complete combustion of butan-1-ol, using the information from Table 10 of the Data Booklet. *[3]*

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(d) Based on the types of intermolecular force present, explain why butan-1-ol has a higher boiling point than butanal. *[2]*

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4. Hypochlorous acid, HOCl(aq), is an example of a weak acid.

(a) State the expression for the ionic product constant of water, K_w. *[1]*

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(b) A household bleach contains sodium hypochlorite, NaOCl(aq), at a concentration of 0.705 mol dm^{-3}. The hypochlorite ion, $OCl^-(aq)$ is a weak base.

$$OCl^-(aq) + H_2O(l) \rightleftharpoons HOCl(aq) + OH^-(aq)$$

(i) The pK_a value of HOCl(aq) is 7.52. Determine the K_b value of $OCl^-(aq)$ assuming a temperature of 298 K. *[1]*

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(ii) Determine the concentration of $OH^-(aq)$, in mol dm^{-3}, at equilibrium and state **one** assumption made in arriving at your answer other than a temperature of 298 K. *[3]*

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(Question 4 continued)

(iii) Calculate the pH of the bleach. *[2]*

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5. (a) Deduce and explain the sign of the entropy change for the following reaction.

$$CO(g) + 2H_2(g) \rightarrow CH_3OH(l)$$ *[2]*

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(b) Consider the reaction:

$$CuS(s) + H_2(g) \rightarrow Cu(s) + H_2S(g)$$

Given:

	$H_2S(g)$	**$CuS(s)$**
$\Delta G_f^{\ominus}$ / kJ mol^{-1}	–33.6	–53.6
$\Delta H_f^{\ominus}$ / kJ mol^{-1}	–20.6	–53.1

(i) Suggest why the $\Delta H_f^{\ominus}$ values for $H_2(g)$ and $Cu(s)$ are not given in the table. *[1]*

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(ii) Determine the standard enthalpy change at 298 K for the reaction. *[1]*

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(This question continues on the following page)

(Question 5 continued)

(iii) Determine the standard free energy change at 298 K for the reaction. Deduce whether or not the reaction is spontaneous at this temperature. *[2]*

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(iv) Determine the standard entropy change at 298 K for the reaction. *[1]*

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(v) Estimate the temperature, in K, at which the standard change in free energy equals zero. You should assume that the values of the standard enthalpy and entropy changes are not affected by the change in temperature. *[1]*

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SECTION B

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

6. (a) Describe the acid-base character of the oxides of the period 3 elements, Na to Cl. For the compounds sodium oxide and phosphorus(V) oxide, state the balanced chemical equations for the reaction of each oxide with water. *[4]*

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(Question 6 continued)

(b) Consider the structure and bonding in $MgCl_2$ and PCl_5.

(i) State and explain the difference in the electrical conductivity in the liquid state of the two chlorides. *[3]*

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(ii) Predict an approximate pH value for the solutions formed by adding each chloride separately to water. Explain your answer. *[4]*

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(Question 6 continued)

(c) For each of the species PBr_3 and SF_6:

(i) deduce the Lewis structure.

(ii) predict the shape and bond angle.

(iii) predict and explain the molecular polarity. *[8]*

PBr_3	**SF_6**
(i) Lewis structure:	(i) Lewis structure:
(ii) Shape: . . . . . Bond angle:	(ii) Shape: . . . . . Bond angle: . . . . .
(iii) Polarity: . . . . . Explanation:	(iii) Polarity: . . . . . Explanation: . . . .

(This question continues on the following page)

(Question 6 continued)

(d) (i) Compare the formation of sigma (σ) and pi (π) bonds between the carbon atoms in a molecule of ethyne. *[2]*

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(ii) Identify the number of sigma and pi bonds present in *trans*-but-2-ene-1,4-dioic acid. *[1]*

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(iii) Explain why the melting point of *trans*-but-2-ene-1,4-dioic acid is higher than that of *cis*-but-2-ene-1,4-dioic acid. *[1]*

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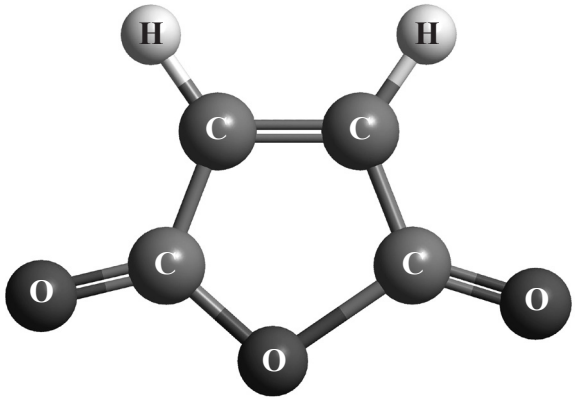
(Question 6 continued)

(iv) Explain why *cis*-but-2-ene-1,4-dioic acid forms *cis*-but-2-ene-1,4-dioic anhydride when heated, whereas no cyclic anhydride forms when *trans*-but-2-ene-1,4-dioic acid is heated. *[1]*



cis-but-2-ene-1,4-dioic anhydride

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(e) Deduce the hybridization of each **oxygen** atom in *cis*-but-2-ene-1,4-dioic acid. *[1]*

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7. Chromium is a typical transition metal with many uses.

(a) Distinguish between the terms *oxidation* and *reduction* in terms of oxidation numbers. *[1]*

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(b) State the names of Cr_2O_3 and CrO_3. *[2]*

Cr_2O_3: . . . . . .

CrO_3: . . . . . .

(c) (i) Define the term *oxidizing agent*. *[1]*

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(ii) $Cr_2O_7^{2-}(aq)$ and $I^-(aq)$ ions react together in the **presence of acid** to form $Cr^{3+}(aq)$ and $IO_3^-(aq)$ ions. Deduce the balanced chemical equation for this redox reaction and identify the species that acts as the oxidizing agent. *[3]*

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(This question continues on the following page)

(Question 7 continued)

(d) A voltaic cell is constructed as follows. One half-cell contains a platinum electrode in a solution containing $K_2Cr_2O_7$ and H_2SO_4. The other half-cell contains an iron electrode in a solution containing Fe^{2+} ions. The two electrodes are connected to a voltmeter and the two solutions by a salt bridge.

(i) Draw a diagram of the voltaic cell, labelling the positive and negative electrodes (cathode and anode) and showing the direction of movement of the electrons and ions. Deduce an equation for the reaction occurring in each of the half-cells, and the equation for the overall cell reaction. *[5]*

(ii) Define the term *standard electrode potential*. *[1]*

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(iii) Calculate the cell potential, in V, under standard conditions, using information from Table 14 of the Data Booklet. *[1]*

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(Question 7 continued)

(e) (i) State **two** characteristic properties of transition elements. *[2]*

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(ii) State the type of bond formed by a ligand and identify the feature that enables it to form this bond. *[2]*

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(iii) Explain why the complex $[Cr(H_2O)_6]^{3+}$ is coloured. *[3]*

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(Question 7 continued)

(iv) Draw an orbital box diagram (arrow-in-box notation) showing the electrons in the 4s and 3d sub-levels in chromium metal. *[1]*

(f) Chromium is often used in electroplating. State what is used as the positive electrode (anode), the negative electrode (cathode) and the electrolyte in the chromium electroplating process. *[3]*

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

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(b) Nitrogen monoxide, NO, is involved in the decomposition of ozone according to the following mechanism.

$$O_3 \rightarrow O_2 + O\bullet$$
$$O_3 + NO \rightarrow NO_2 + O_2$$
$$NO_2 + O\bullet \rightarrow NO + O_2$$

Overall: $2O_3 \rightarrow 3O_2$

State and explain whether or not NO is acting as a catalyst. *[2]*

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(c) (i) Define the term *endothermic reaction*. *[1]*

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(Question 8 continued)

(ii) Sketch the Maxwell-Boltzmann energy distribution curve for a reaction with and without a catalyst, and label both axes. *[3]*

(d) Nitrogen reacts with hydrogen to form ammonia in the Haber process, according to the following equilibrium.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \qquad \Delta H^{\ominus} = -92.6 \text{ kJ}$$

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

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(ii) A high pressure such as 1000 atm and a low temperature such as 300 K can produce a high yield of ammonia. Discuss how these conditions compare with the actual conditions of pressure and temperature used in the Haber process. *[4]*

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(Question 8 continued)

(e) $BF_3(g)$ reacts with $NH_3(g)$ to form $F_3BNH_3(g)$ according to the equation below.

$$BF_3(g) + NH_3(g) \rightarrow F_3BNH_3(g)$$

(i) Identify the type of bond present between BF_3 and NH_3 in $F_3BNH_3(g)$ and state another example of a compound with this type of bonding. *[2]*

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(ii) The table below shows initial rates of reaction for different concentrations of each reactant for this reaction at temperature, *T*.

Experiment	**$[BF_3(g)]$ / mol dm^{-3}**	**$[NH_3(g)]$ / mol dm^{-3}**	**Initial rate / mol dm^{-3} s^{-1}**
1	1.00×10^{-1}	6.67×10^{-2}	2.27×10^{-2}
2	1.00×10^{-1}	3.75×10^{-2}	1.28×10^{-2}
3	2.50×10^{-1}	2.50×10^{-1}	2.13×10^{-1}
4	3.00×10^{-1}	1.00×10^{-1}	1.02×10^{-1}

Deduce the rate expression, the overall order of the reaction and determine the value of *k*, the rate constant, with its units, using the data from Experiment 4. *[3]*

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(This question continues on the following page)

(Question 8 continued)

(f) The following is a proposed mechanism for the reaction of $NO(g)$ with $H_2(g)$.

Step 1: $2NO(g) \rightarrow N_2O_2(g)$

Step 2: $N_2O_2(g) + H_2(g) \rightarrow N_2O(g) + H_2O(g)$

(i) Identify the intermediate in the reaction. *[1]*

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(ii) The observed rate expression is rate $= k[NO]^2[H_2]$. Assuming that the proposed mechanism is correct, comment on the relative speeds of the two steps. *[1]*

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(g) The following two-step mechanism has been suggested for the reaction of $NO_2(g)$ with $CO(g)$, where $k_2 >> k_1$.

Step 1: $NO_2(g) + NO_2(g) \xrightarrow{k_1} NO(g) + NO_3(g)$

Step 2: $NO_3(g) + CO(g) \xrightarrow{k_2} NO_2(g) + CO_2(g)$

Overall: $NO_2(g) + CO(g) \longrightarrow NO(g) + CO_2(g)$

The experimental rate expression is rate $= k_1[NO_2]^2$. Explain why this mechanism produces a rate expression consistent with the experimentally observed one. *[2]*

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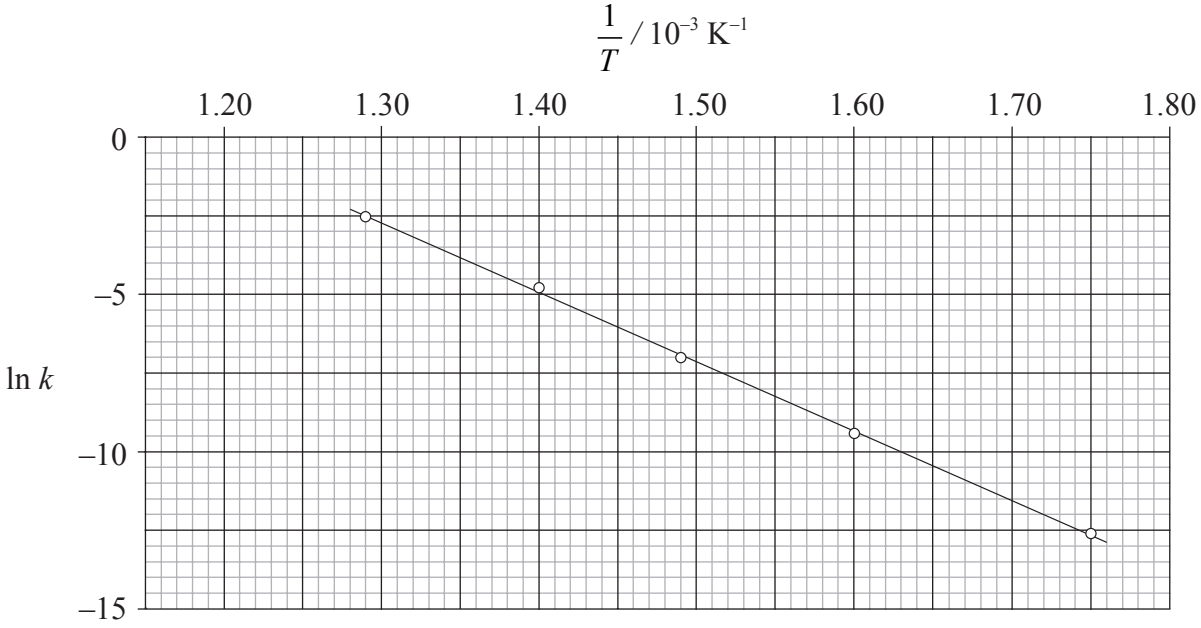
(Question 8 continued)

(h) $HI(g)$ decomposes into $H_2(g)$ and $I_2(g)$ according to the reaction below.

$$2HI(g) \rightarrow H_2(g) + I_2(g)$$

The reaction was carried out at different temperatures and a value of the rate constant, k, was obtained for each temperature. A graph of $\ln k$ against $\frac{1}{T}$ is shown below.



Calculate the activation energy, E_a, for the reaction using these data and Table 1 of the Data Booklet showing your working. *[4]*

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9. (a) One example of a homologous series is the alcohols. Describe **two** features of a homologous series. *[2]*

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(b) Consider the following reactions.

$(CH_3)_2CHCH_2CH_2CH_2OH \xrightarrow{CH_3COOH/H^+} CH_3COOCH_2CH_2CH_2CH(CH_3)_2$

D **G**

$(CH_3)_2CHCH_2CH_2CHO$

E

$(CH_3)_2CHCH_2CH_2COOH \xrightarrow{(CH_3)_2NH}$ **H**

F

(i) State the IUPAC names of each of the compounds, **D**, **E**, **F** and **G**. *[2]*

D: . . . . . .

E: . . . . . .

F: . . . . . .

G: . . . . . .

(This question continues on the following page)

(Question 9 continued)

(ii) Deduce the structural formula of **H**. *[1]*

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(iii) State the reagents and reaction conditions used to convert **D** to **E** and **D** to **F** directly. *[2]*

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(iv) Discuss the volatility of **E** compared to **F**. *[2]*

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(Question 9 continued)

(c) An important environmental consideration is the appropriate disposal of cleaning solvents. An environmental waste treatment company analysed a cleaning solvent, **J**, and found it to contain the elements carbon, hydrogen and chlorine only. The chemical composition of **J** was determined using different analytical chemistry techniques.

Combustion Reaction:

Combustion of 1.30 g of **J** gave 0.872 g CO_2 and 0.089 g H_2O.

Precipitation Reaction with $AgNO_3(aq)$:

0.535 g of **J** gave 1.75 g AgCl precipitate.

(i) Determine the percentage by mass of carbon and hydrogen in **J**, using the combustion data. *[3]*

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(ii) Determine the percentage by mass of chlorine in **J**, using the precipitation data. *[1]*

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(This question continues on the following page)

(Question 9 continued)

(iii) The molar mass was determined to be 131.38 g mol^{-1}. Deduce the molecular formula of **J**. *[3]*

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(d) Polyesters can be made by condensing diols with dicarboxylic acids. One example of a polyester is polyethene terephthalate (known as Dacron® or Terylene in different parts of the world), which is formed from benzene-1,4-dicarboxylic acid and ethane-1,2-diol.

(i) Draw the structures of the two monomers, benzene-1,4-dicarboxylic acid and ethane-1,2-diol and the polymer polyethene terephthalate. *[2]*

(This question continues on the following page)

(Question 9 continued)

(ii) Climbing suits, sleeping bags and other outdoor clothing all contain polyester type materials. Fibres of nylon (which is a polyamide) are used in the manufacture of climbing ropes. State **one** property of a polyester and **one** property of nylon that makes them suitable for these purposes. *[2]*

Polyester:

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Nylon:

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(e) An elimination mechanism occurs for the dehydrohalogenation reaction of 2-bromo-2-methylbutane with OH^-. Draw the structures of 2-bromo-2-methylbutane and the two products, 2-methylbut-2-ene (major) and 2-methylbut-1-ene (minor). Explain the mechanism for the formation of either product, using curly arrows to represent the movement of electron pairs. *[5]*

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