UNIVERSITY OF CAMBRIDGE INTERNATIONAL EXAMINATIONS
General Certificate of Education Advanced Level

CANDIDATE NAME

CENTRE NUMBER

CANDIDATE NUMBER

CHEMISTRY **9701/41**

Paper 4 Structured Questions **May/June 2011**

2 hours

Candidates answer on the Question Paper.

Additional Materials: Data Booklet

READ THESE INSTRUCTIONS FIRST

Write your Centre number, candidate number and name on all the work you hand in.
Write in dark blue or black pen.
You may use a pencil for any diagrams, graphs or rough working.
Do not use staples, paper clips, highlighters, glue or correction fluid.
DO **NOT** WRITE IN ANY BARCODES.

Section A
Answer **all** questions.

Section B
Answer **all** questions.

You may lose marks if you do not show your working or if you do not use appropriate units.
A Data Booklet is provided.

At the end of the examination, fasten all your work securely together.
The number of marks is given in brackets [ ] at the end of each question or part question.

For Examiner's Use	
1	
2	
3	
4	
5	
6	
7	
8	
9	
Total	

This document consists of **18** printed pages and **2** blank pages.

Section A

For Examiner's Use

Answer **all** questions in the spaces provided.

1 Taken together, nitrogen and oxygen make up 99% of the air. Oxygen is by far the more reactive of the two gases, and most of the substances that react with air combine with the oxygen rather than with the nitrogen.

(a) State **one** reason why the molecule of nitrogen, N_2, is so unreactive.

.....[1]

Despite the apparent lack of reactivity of N_2, nitrogen atoms have been found to form bonds with almost all of the elements in the Periodic Table. Lithium metal reacts with nitrogen gas at room temperature to give lithium nitride, Li_3N. Magnesium produces magnesium nitride, Mg_3N_2, as well as magnesium oxide, when heated in air.

(b) Calculate the lattice energy of magnesium nitride using the following data, in addition to relevant data from the *Data Booklet*.

enthalpy change	value/kJ mol^{-1}
atomisation of Mg(s)	+148
total of electron affinities for the change $N(g) \longrightarrow N^{3-}(g)$	+2148
enthalpy of formation of $Mg_3N_2(s)$	–461

lattice energy = ...kJ mol^{-1} [3]

(c) Lithium reacts readily with nitrogen, and because of this Li_3N has been considered as a possible intermediate in the 'fixing' of nitrogen to make ammonia-based fertilisers.

For Examiner's Use

$$N_2(g) \xrightarrow{+\ Li} Li_3N \xrightarrow{+\ H_2O} NH_3 + \mathbf{A}$$

(i) Construct an equation for the reaction between Li_3N and H_2O, and hence identify compound **A**.

.....

(ii) Using your knowledge of the Haber process, consider **one** advantage and **one** disadvantage of using lithium as a means of fixing nitrogen, rather than the Haber process.

advantage of the lithium method

.....

disadvantage of the lithium method

.....

[3]

(d) Another possible advantage of Li_3N is that it contains a large percentage by mass of nitrogen. Another fertiliser that contains a large percentage by mass of nitrogen is urea, NH_2CONH_2.

(i) Calculate and compare the percentages by mass of nitrogen in Li_3N and NH_2CONH_2.

.....

.....

.....

(ii) What *class* of organic compound is urea?

.....

(iii) Write an equation for the production of ammonia by the reaction between urea and water.

.....

(iv) Urea can be applied directly to the soil either before or during the growing of crops.
What would be a major **disadvantage** of using lithium nitride in this way?

.....

.....

[5]

[Total: 12]

2 **(a)** State briefly what is meant by the following terms.

For Examiner's Use

(i) reversible reaction

.....

(ii) dynamic equilibrium

.....

.....

[2]

(b) Water ionises to a small extent as follows.

$$H_2O(l) \rightleftharpoons H^+(aq) + OH^-(aq) \qquad \Delta H = +58\,kJ\,mol^{-1}$$

(i) Write an expression for K_c for this reaction.

.....

(ii) Write down the expression for K_w, the ionic product of water, and explain how this can be derived from your K_c expression in **(i)**.

.....

.....

(iii) State and explain how the value of K_w for hot water will differ from its value for cold water.

.....

.....

[3]

(c) K_w can be used to calculate the pH of solutions of strong and weak bases.

(i) Use the value of K_w in the *Data Booklet* to calculate the pH of $0.050\,mol\,dm^{-3}$ NaOH.

pH = ...

Ammonia ionises slightly in water as follows.

$$NH_3(aq) + H_2O(l) \rightleftharpoons NH_4^+(aq) + OH^-(aq)$$

The following expression applies to this equilibrium.

$$[H_2O] \times K_c = [NH_4^+][OH^-]/[NH_3] = 1.8 \times 10^{-5}\,mol\,dm^{-3}$$

(ii) Calculate $[OH^-(aq)]$ in a 0.050 mol dm^{-3} solution of NH_3. You may assume that only a small fraction of the NH_3 ionises, so that $[NH_3]$ at equilibrium remains at 0.050 mol dm^{-3}.

For Examiner's Use

$[OH^-(aq)]$ = ...

(iii) Use the value of K_w in the *Data Booklet*, and your answer in **(ii)**, to calculate $[H^+(aq)]$ in 0.050 mol dm^{-3} $NH_3(aq)$.

$[H^+(aq)]$ = ...

(iv) Calculate the pH of this solution.

pH = ...
[6]

[Total: 11]

[Turn over

3 **(a)** State and explain the variation in the oxidation numbers of the chlorides of the elements Na, Mg, A*l* and Si.

For Examiner's Use

.....

.....

.....

.....[2]

(b) Describe the reaction of phosphorus(V) chloride with water, and write an equation for the reaction.

.....

.....[2]

(c) When microwave radiation is passed through phosphorus(III) chloride, PCl_3, at low pressure, a new chloride of phosphorus, **B**, is formed.
B contains 69.6% by mass of chlorine and 30.4% by mass of phosphorus, and its M_r is approximately 200.

(i) Calculate the empirical and molecular formulae of **B**.

.....

(ii) Assuming phosphorus and chlorine show their typical valencies, draw the displayed formula of **B**, showing all bonds and lone pairs.

.....

(iii) Calculate the oxidation number of phosphorus in **B**.

.....

(iv) One mole of **B** reacts with four moles of water.
Suggest the structure of the phosphorus-containing product of this reaction.

.....
[6]

[Total: 10]

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[Turn over

For Examiner's Use

4 The combustion of fuels in motor vehicles, trains, aeroplanes and power stations produces the pollutant gas NO_2.

(a) Write an equation to show how NO_2 is formed in these situations.

.....[1]

(b) **(i)** How is the NO_2 removed from the exhaust gases of motor vehicles?

.....

(ii) Write an equation for this process.

.....
[2]

(c) Suggest whether the production of the pollutant NO_2 would be reduced if fossil fuels were replaced by hydrogen as a fuel for combustion. Explain your answer.

.....

.....[1]

(d) In the atmosphere, NO_2 acts as a catalyst for the oxidation of SO_2 to SO_3.

$$SO_2(g) + \tfrac{1}{2}\,O_2(g) \xrightarrow{NO_2} SO_3(g)$$

(i) What is the environmental significance of this reaction?

.....

The oxidation takes place in two steps. The initial reaction is that between NO_2 and SO_2.

reaction 1 $NO_2(g) + SO_2(g) \rightleftharpoons NO(g) + SO_3(g)$ $\quad \Delta H = -168\,kJ\,mol^{-1}$

(ii) Write an equation to show how the NO_2 is regenerated in the second step of the oxidation.

.....

(iii) Write an expression for the equilibrium constant, K_p for *reaction 1*, stating its units.

K_p =

units .....

(iv) If equal amounts of $NO_2(g)$ and $SO_2(g)$ are allowed to react at room temperature, it is found that 99.8% of the gases have been converted into products at equilibrium. Calculate a value for K_p.

K_p = ...

(v) The temperature of the atmosphere decreases with height. How will this affect the position of the equilibrium in *reaction 1*? Explain your answer.

For Examiner's Use

.....

.....

[7]

[Total: 11]

5 **(a)** There are several ways of introducing chlorine atoms into organic molecules. State the reagents and conditions necessary to carry out the following transformations.

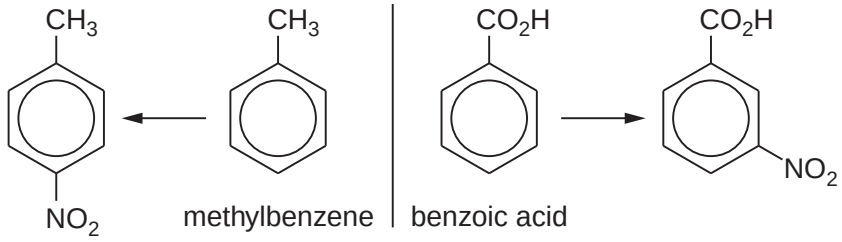
For Examiner's Use

transformation	reagents + conditions
$C_2H_4 \longrightarrow C_2H_5Cl$	
$C_2H_5OH \longrightarrow C_2H_5Cl$	
$C_2H_6 \longrightarrow C_2H_5Cl$	
$C_2H_4 \longrightarrow C_2H_4Cl_2$	
$CH_3CO_2H \longrightarrow CH_3COCl$	
	
	

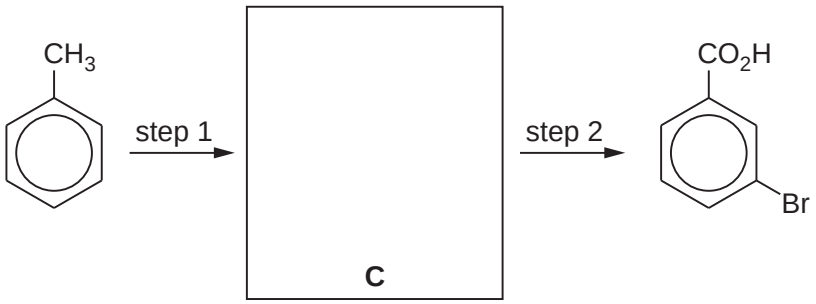
[6]

(b) **(i)** When treated with concentrated HNO_3 + H_2SO_4 at 55 °C, benzene produces nitrobenzene.
Outline the mechanism of this reaction. You should include all charges, and use curly arrows to represent the movement of electron pairs.

In aromatic substitution of monosubstituted benzenes, the orientation of an incoming group depends on the nature of the group already attached to the ring.
For example, using the same reagents and conditions as in **(i)**, methylbenzene and benzoic acid produce the following nitro compounds.



(ii) Using this information as an aid, suggest a structure for compound **C** in the following synthesis of 3-bromobenzoic acid.



(iii) Suggest reagents and conditions for steps 1 and 2.

step 1	step 2

[6]

[Total: 12]

For Examiner's Use

6 **(a)** The reaction producing tri-iodomethane (iodoform) can be used as a test for the presence of certain groups within a molecule.

(i) State the reagents and conditions used for this reaction.

.....

(ii) Write the structural formula of **one** functional group that would give a positive result with this iodoform reaction.

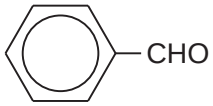
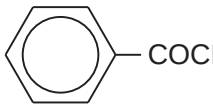
.....

(iii) What do you observe in a positive test?

.....

.....

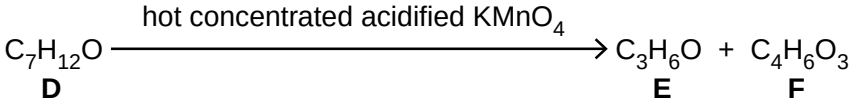
(iv) In the following table place a tick (✓) in the column against each compound that would give a positive result with this test, and a cross (✗) against each compound that would give a negative result.

compound	result
CH_3OH	
CH_3CH_2OH	
CH_3CHO	
CH_3CO_2H	
	
	

[6]

(b) The iodoform test can be used, along with other reactions, to work out the structures of unknown compounds.
Use the information in the table below to deduce the structures of the compounds in the following scheme, and draw these structures in the boxes provided.

For Examiner's Use



Results of tests (✓ indicates a positive result; ✗ indicates a negative result)

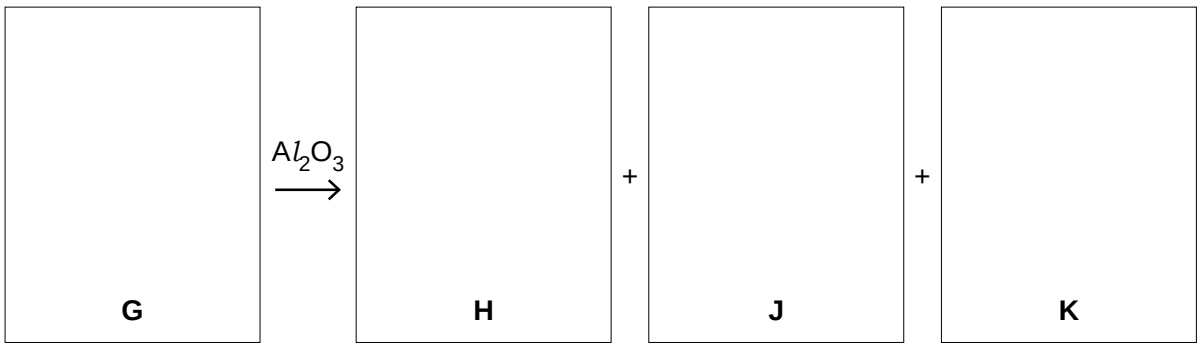
test	results of tests with each compound		
	D	**E**	**F**
iodoform	✗	✓	✓
Fehling's solution	✓	✗	✗
2,4-dinitrophenyl-hydrazine reagent	✓	✓	✓
Na_2CO_3(aq)	✗	✗	✓

structures

D($C_7H_{12}O$) **E**(C_3H_6O) **F**($C_4H_6O_3$)

[3]

(c) Treatment of compound **F** with $NaBH_4$ gives compound **G**, $C_4H_8O_3$. Heating **G** with Al_2O_3 gives a mixture of three isomeric unsaturated carboxylic acids **H**, **J** and **K**, $C_4H_6O_2$, two of which are stereoisomers of each other.
Suggest structures for **G**, **H**, **J**, and **K**, and name the type of stereoisomerism shown.



type of stereoisomerism .....[5]

[Total: 14]

Section B

For Examiner's Use

Answer **all** questions in the spaces provided.

7 Enzymes are a special group of protein molecules present in large amounts in living organisms. Enzymes behave as catalysts but, unlike inorganic catalysts, they generally catalyse only one particular reaction.

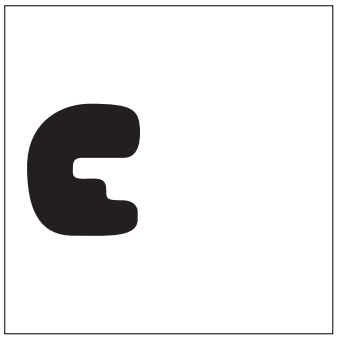
(a) Inorganic catalysts often work better on heating, but enzymes rarely work at temperatures much above 45°C. Explain why this is the case.

.....

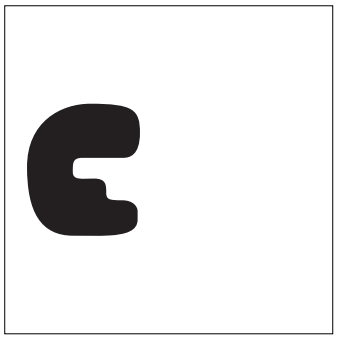
.....

..... [2]

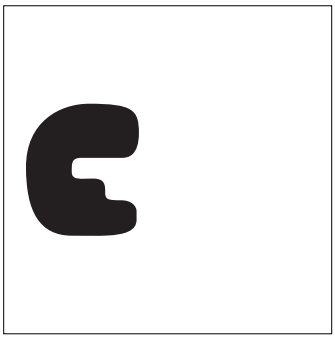
(b) Using the shape below to represent an enzyme, sketch how an enzyme is specific to the breakdown of a particular substrate molecule



enzyme + substrate



enzyme-substrate complex



enzyme + products

[3]

(c) Describe the effects of a competitive, and of a non-competitive inhibitor on the interaction between enzyme and substrate.

For Examiner's Use

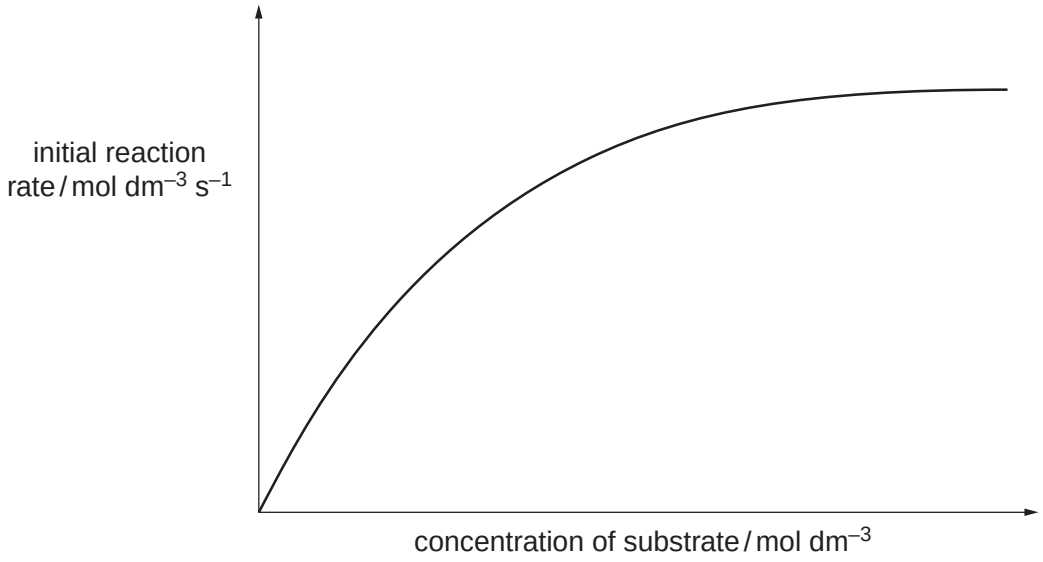
.....

.....

.....

.....[2]

(d) **(i)** The diagram shown illustrates an enzyme-catalysed reaction. On the diagram sketch the graph that would be obtained if the same reaction was carried out in the presence of a **non-competitive** inhibitor.



(ii) Explain why a **non-competitive** inhibitor has this effect on the reaction.

.....

.....
[3]

[Total: 10]

8 Chromatography is an important analytical technique in chemistry. There is a number of techniques under the general heading of chromatography.

For Examiner's Use

(a) Paper and gas chromatography rely on partition to separate the components in a mixture, whereas thin-layer chromatography uses adsorption.

Explain what is meant by **(i)** *partition* and **(ii)** *adsorption*, in the context of chromatography.

(i) partition .....

.....

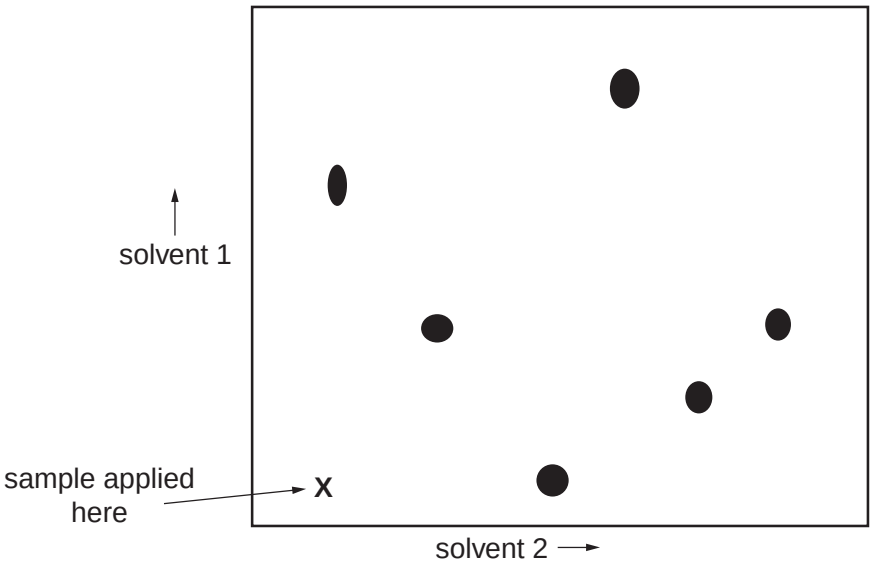
.....

(ii) adsorption .....

.....

.....[2]

(b) In paper or thin-layer chromatography, better separation may be achieved by running the chromatogram in one solvent, then turning the paper at right angles and running it in a second solvent. The chromatogram below was produced in this way.



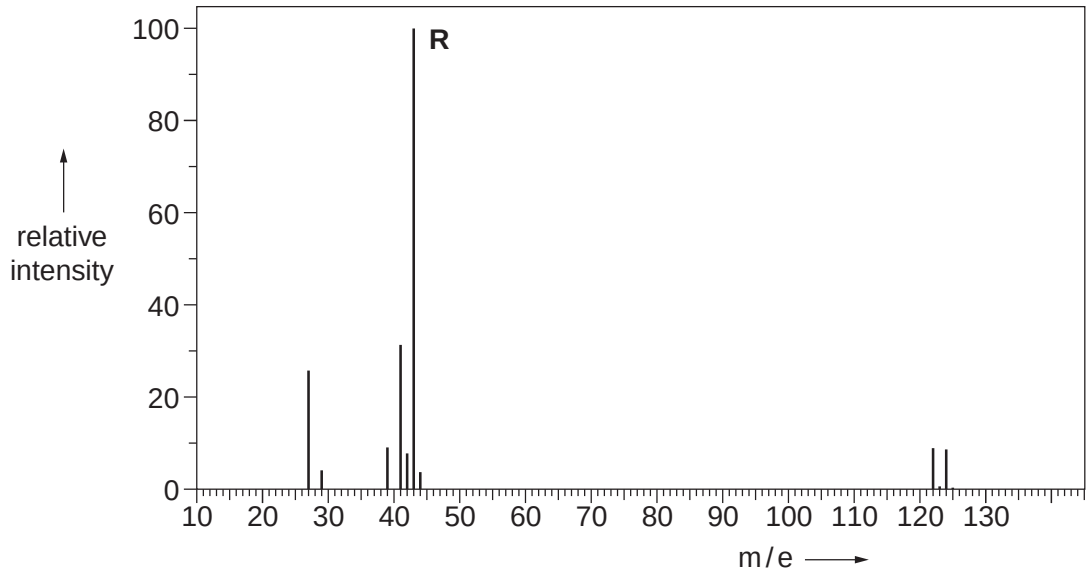
(i) Ring the spot which was insoluble in solvent 1.

(ii) Label as **A** and **B** the spots which were **not** resolved using solvent 1.

[2]

(c) The mass spectrum shown was obtained from a compound of formula C_pH_qX, where *X* represents a halogen atom.

For Examiner's Use



(i) Deduce the identity of *X*, giving a reason.

X is .....

.....

(ii) If the relative heights of the M and M+1 peaks are 9 and 0.3 respectively, calculate the value of *p*. Use this value and the m / e value of the molecular ion to calculate the value of *q*, and hence the molecular formula of the compound. Show your working.

(iii) Suggest a formula for the ion responsible for the peak labelled **R**.

..... [4]

(d) In the fragmentation of alcohols which occurs in a mass spectrometer, small stable, neutral molecules are sometimes produced. Suggest the identity of **two** such molecules, each with an M_r less than 30.

(i) ..... **(ii)** ..... [2]

[Total: 10]

9 In today's world, many traditional materials have been replaced by different sorts of polymers. This includes rigid polymers such as those used in car bodies to replace steel and flexible polymers like those used in textiles to replace cotton or wool.

For Examiner's Use

(a) (i) To form a polymer, what is the **minimum** number of functional groups that the monomer must possess?

.....

(ii) Illustrate your answer to **(i)** with the structure of a possible monomer.

[2]

(b) State **two** differences between addition and condensation polymerisation.

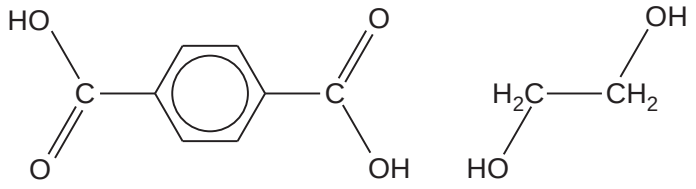
(i) .....

.....

(ii) .....

.....[2]

(c) The polymer formed from the co-polymerisation of the two monomers shown is known as *Terylene.*



benzene-1, 4-dicarboxylic acid **ethane-1-2-diol**

(i) The two monomers react by condensation polymerisation. What other molecule is formed in this reaction?

.....

(ii) Draw the structure of **one** repeat unit of *Terylene.*

For Examiner's Use

(iii) What is the name given to polymers containing the same functional group as *Terylene*?

..... [4]

(d) The monomers ethene and but-1-ene can also co-polymerise to form a polyalkene, but this does not produce a regular alternating structure like *Terylene.* Explain why this is the case, drawing diagrams if you wish.

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.....

[2]

[Total: 10]

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