H2

MINISTRY OF EDUCATION, SINGAPORE
in collaboration with
CAMBRIDGE INTERNATIONAL EDUCATION
General Certificate of Education Advanced Level

CANDIDATE NAME									
CENTRE NUMBER	S					INDEX NUMBER			

0123456789

CHEMISTRY **9476/02**

Paper 2 Structured Questions **For examination from 2026**

SPECIMEN PAPER **2 hours**

You must answer on the question paper.

You will need: Data booklet

INSTRUCTIONS

- Answer **all** questions.
- Use a black or dark blue pen. You may use an HB pencil for any diagrams or graphs.
- Write your name, centre number and index number in the boxes at the top of the page.
- Write your answer to each question in the space provided.
- Do **not** use an erasable pen. Do **not** use correction fluid or tape.
- Do **not** write on any bar codes.
- You may use an approved calculator.

INFORMATION

- The total mark for this paper is 75.
- The number of marks for each question or part question is shown in brackets [ ].

This document has **20** pages. Any blank pages are indicated.

Singapore Examinations and Assessment Board

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[Turn over

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

1 Nitrogen and phosphorus are both found in Group 15 of the Periodic Table. Nitrogen exists in its elemental form as simple molecules, N_2, while phosphorus occurs in one of a number of forms, including 'white' phosphorus and 'red' phosphorus. Some data about these two forms of phosphorus are shown in Table 1.1.

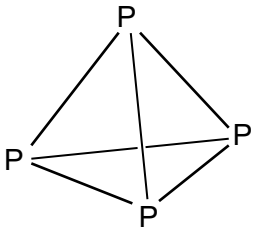
Table 1.1

	'white' phosphorus	**'red' phosphorus**
appearance at room temperature	creamy white solid	red solid
melting point / °C	44	590
solubility in methylbenzene	soluble	insoluble

(a) Draw a 'dot-and-cross' diagram to show the bonding in nitrogen, N_2. Show outer electrons only.

[1]

(b) The corresponding form of phosphorus, P_2, is **not** stable under standard conditions. Instead, 'white' phosphorus consists of molecules with a tetrahedral structure as shown.



'white' phosphorus

(i) Using the data in Table 1.2, calculate the enthalpy change for the conversion of 'white' phosphorus, P_4, to the gaseous diatomic molecule, P_2, shown in equation 1.

equation 1 $\quad P_4(s) \rightarrow 2P_2(g)$

Table 1.2

P–P bond energy	200 kJ mol^{-1}
P≡P bond energy	485 kJ mol^{-1}
enthalpy change of vaporisation of P_4(s)	+12 kJ mol^{-1}

[3]

(ii) The reaction described in equation 1 is **not** spontaneous at 298 K.
At a higher temperature, *T*, the reaction is spontaneous.

Explain why this reaction is spontaneous at *T*.

.....

.....

.....

.....

..... [3]

(c) Suggest the type of structure and bonding in 'red' phosphorus.

.....

..... [1]

(d) N_2H_4 reduces BrO_3^- as shown in equation 2.

equation 2 $3N_2H_4 + 4BrO_3^- \rightarrow 6NO + 4Br^- + 6H_2O$

(i) Consider the changes to the oxidation number of bromine to deduce the total number of moles of electrons transferred in the reaction described in equation 2.

..... [1]

(ii) Use your answer to **1(d)(i)** to deduce the oxidation number of nitrogen in N_2H_4.

..... [1]

[Total: 10]

2 **(a)** Group 2 carbonates decompose endothermically when heated.

(i) Write the equation for the thermal decomposition of magnesium carbonate.

..... [1]

(ii) On Figure 2.1, draw the energy profile diagram for the thermal decomposition of magnesium carbonate.

Label:

- the reactants and products
- the enthalpy change of reaction, ΔH
- the activation energy, E_a.

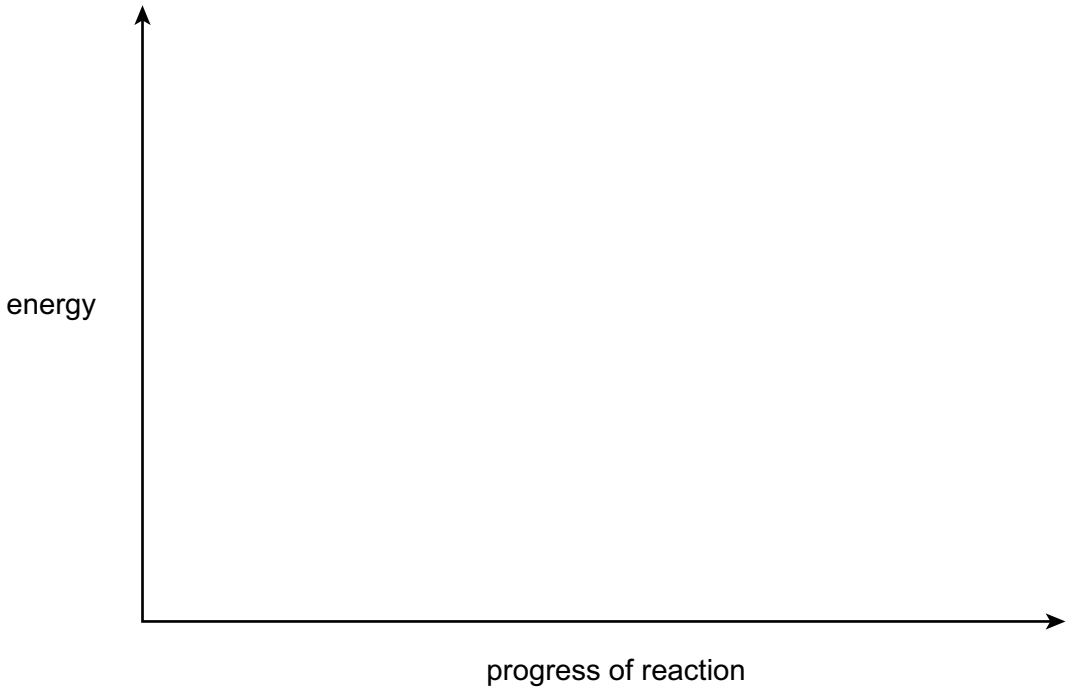


Figure 2.1

[3]

(iii) There is a trend in the decomposition temperature of Group 2 carbonates down the group.

State and explain this trend.

trend .....

explanation .....

.....

.....

.....

.....

[4]

(b) Dolomite is a carbonate-containing mineral with formula $MgZ(CO_3)_2$ where *Z* is a metal ion.

Dolomite is insoluble in water but dissolves in acid. The ionic equation for the reaction between hydrogen ions and carbonate ions is shown.

$$2H^+(aq) + CO_3^{2-}(aq) \rightarrow CO_2(g) + H_2O(l)$$

A 5.00 g sample of dolomite is dissolved in 30.0 cm^3 of 5.00 mol dm^{-3} hydrochloric acid. The acid is in excess.

The resulting solution is made up to 100 cm^3 in a volumetric flask using deionised water, and labelled solution **A**. 10.0 cm^3 of solution **A** is titrated against 0.100 mol dm^{-3} sodium hydroxide, NaOH. An average titre of 41.50 cm^3 is obtained.

(i) Calculate the amount in moles of hydrochloric acid in 100 cm^3 of solution **A**.

[1]

(ii) Calculate the amount in moles of hydrochloric acid that reacts with the 5.00 g sample of dolomite.

[2]

(iii) Calculate the mass of carbonate ions in the 5.00 g sample of dolomite.

[2]

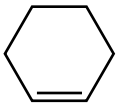
(iv) Determine the molar mass of the metal ion *Z*.

Give your answer to two significant figures.

[3]

[Total: 16]

3 Cyclohexene behaves as a typical alkene.



cyclohexene

(a) Deduce the total numbers of σ bonds and π bonds in a molecule of cyclohexene.

number of σ bonds .....

number of π bonds .....
[2]

(b) Cyclohexene reacts with liquid bromine, and with bromine water, at room temperature in the absence of ultraviolet light.

(i) Explain why alkenes react with bromine via electrophilic addition but alkanes do not.

.....

.....

..... [2]

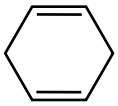
(ii) Write an equation for the reaction between cyclohexene and liquid bromine.

..... [1]

(iii) When cyclohexene is added to bromine water, the reaction produces two additional products, **X** and HBr. Deduce the structure of the additional organic product, **X**. Ignore any stereochemistry.

[1]

(c) Cyclohexa-1,4-diene also displays reactivity typical of alkenes.



cyclohexa-1,4-diene

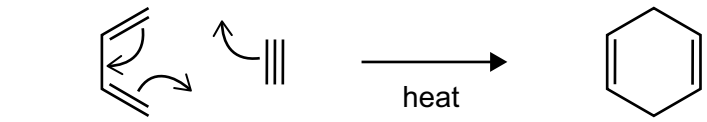
When bromine adds across a C=C double bond, the two bromine atoms bond to opposite faces of the molecule.

Draw the **three** different possible products when one molecule of cyclohexa-1,4-diene reacts with two molecules of bromine.

Show the six-membered carbon ring as a hexagon in the plane of the paper and use wedged ◄ and dashed bonds ⁻⁻ to bromine to show the stereochemistry.

[3]

(d) Cyclohexa-1,4-diene can be made by heating buta-1,3-diene with ethyne. Figure 3.1 shows the movement of electron pairs, represented by curly arrows, needed to generate the cyclohexa-1,4-diene in a single step.



buta-1,3-diene ethyne

Figure 3.1

(i) In a similar type of reaction, cyclohexene can be formed from two alkenes.

Suggest the name of the alkene that would react with buta-1,3-diene to form cyclohexene in this type of reaction.

..... [1]

(ii) In another similar reaction, penta-1,3-diene reacts with propene to form two products that are structural isomers.

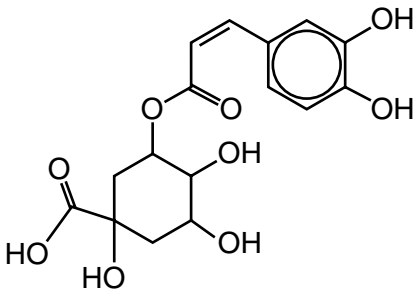
Deduce the structures of these two isomers.

[2]

[Total: 12]

  [Turn over

4 Coffee beans contain chlorogenic acid.



chlorogenic acid

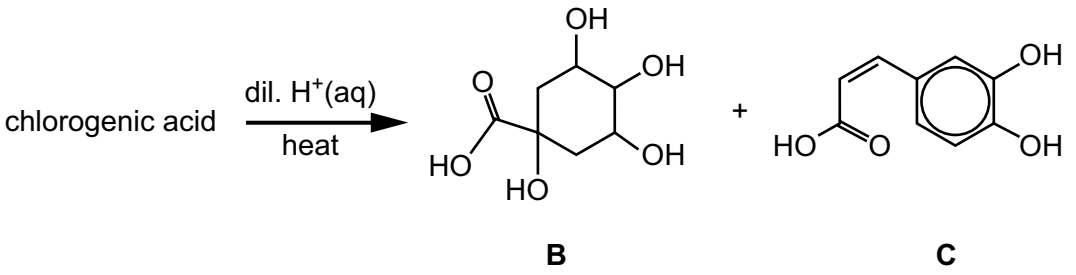
(a) (i) Deduce the molecular formula of chlorogenic acid.

..... [1]

(ii) Deduce the number of moles of $H_2(g)$ that is evolved when 1 mol of chlorogenic acid reacts with an excess of sodium metal.

..... [1]

(b) On heating with dilute aqueous acid, chlorogenic acid produces two compounds, **B** and **C**.



B **C**

Figure 4.1

(i) State the type of reaction chlorogenic acid undergoes in Figure 4.1.

..... [1]

(ii) Identify the functional group in **C** that gives a positive test with cold, alkaline $KMnO_4$.

..... [1]

When compound **B** is heated with concentrated H_3PO_4, compound **D**, $C_7H_6O_3$, forms.

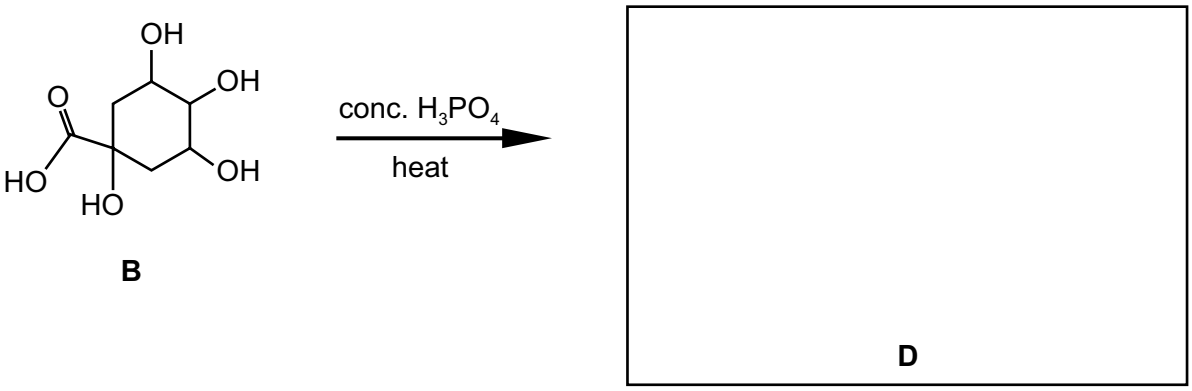


Figure 4.2

When compound **D** is treated with Na_2CO_3(aq), carbon dioxide evolves.

Compound **D** decolourises Br_2(aq) giving a white precipitate.

Compound **D** does **not** react with cold, alkaline $KMnO_4$.

(iii) Name the functional groups in compound **D** that react with the following.

Na_2CO_3(aq) .....

Br_2(aq) .....

[2]

(iv) Suggest the structure for compound **D**. Draw the structure of **D** in the box in Figure 4.2.

[1]

(v) When compound **C** is treated with an excess of Br_2(aq), compound **E** is produced.

Suggest the structure for compound **E**. Draw the structure of **E** in the box in Figure 4.3.

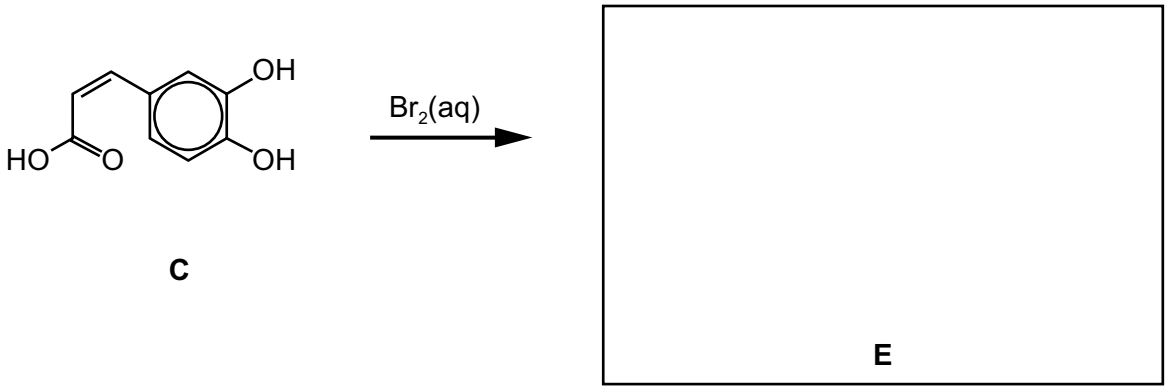


Figure 4.3

[1]

[Total: 8]

5 Transition elements show typical properties that distinguish them from s-block elements. These properties include variable oxidation states in their compounds and the formation of coloured complex ions.

Table 5.1 gives data about some physical properties of the elements calcium, iron and copper.

Table 5.1

property	calcium	iron	copper
relative atomic mass	40.1	55.8	63.5
atomic radius (metallic) / nm	0.197	0.126	0.128
ionic radius (2+) / nm	0.099	0.076	0.069
melting point / K	1112	1808	1358
density / g cm^{-3}	1.54	7.86	8.92
electrical conductivity / $\times 10^6$ S cm^{-1}	0.298	0.100	0.596

(a) Explain why the atomic radii of iron and copper are similar to each other.

.....

.....

.....

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.....

..... [4]

(b) Use relevant data from Table 5.1 to explain why the densities of iron and copper are significantly greater than that of calcium. You do **not** need to include calculations in your answer.

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.....

.....

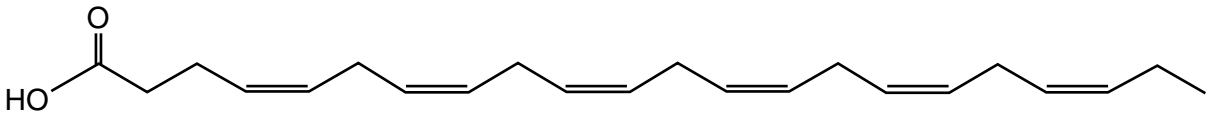
..... [3]

[Total: 7]

Turn over

6 There is evidence to suggest that omega-3 oils help protect us from schizophrenia and depression, and even improve learning and memory. Omega-3 oils are glyceryl esters of omega-3 fatty acids.

One omega-3 fatty acid is cervonic acid.

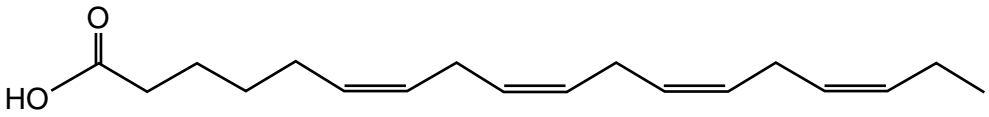


cervonic acid

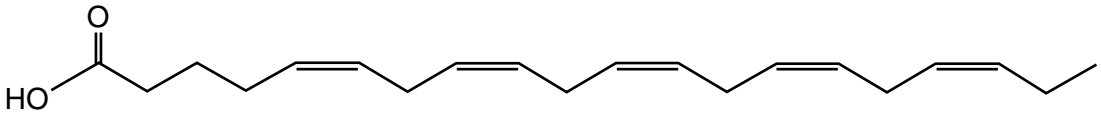
(a) Name the configuration of the C=C double bonds present in this molecule.

..... [1]

The systematic name of cervonic acid (ignoring *cis-trans* isomerism) is docosa-4,7,10,13,16,19-hexaenoic acid. 'Docosa' indicates that there is a 22-carbon chain. The numbers indicate the carbon atom where the C=C double bonds start, counting from the carboxylic acid ($-CO_2H$) functional group. 'Hexaen' indicates that there are six double bonds in the chain. Two other omega-3 fatty acids are stearidonic acid and timnodonic acid.



stearidonic acid



timnodonic acid

(b) 'Octadeca' indicates that there is an 18-carbon chain. Give the systematic name for stearidonic acid. Ignore *cis-trans* isomerism.

..... [1]

(c) State the number of *cis-trans* isomers of timnodonic acid, including the molecule shown.

..... [1]

(d) Name the intermolecular force that is formed between the hydrocarbon chains of the fatty acids.

..... [1]

(e) Cervonic acid is also known as DHA (short-form for docosa-4,7,10,13,16,19-hexaenoic acid). DHA is abundant in the human brain and is said to play a critical role in its function. DHA is not produced by the brain but can be obtained from food sources. It is suggested that adults should consume about 500 mg of DHA per day for good health.

Table 6.1 shows the nutrition label on a pack of eggs.

Table 6.1

nutrition information		
servings per package: 10	**serving size**: 50 g / 1 whole egg	
	per serving	**per 100 g**
energy	72 kcal	144 kcal
protein	6.8 g	13.6 g
total fat	5.0 g	10.0 g
– total omega-3 fatty acids	0.3 g	0.6 g
• DHA	50 mg	100 mg
cholesterol	150 mg	300 mg
carbohydrate	0.4 g	0.8 g
dietary fibre	0 g	0 g
sodium	70 mg	140 mg

Fat should not exceed 25% of an adult's total energy intake per day.

(i) Calculate the mass of fat intake allowed per day based on a typical diet of 2000 kcal per day, given that every 1 g of fat produces 9 kcal in the body.

[1]

(ii) Consuming 10 eggs per day would meet the suggested DHA requirement.

Discuss whether consuming 10 eggs per day is an appropriate way to meet the DHA requirement, considering your answer in **6(e)(i)** and the information provided.

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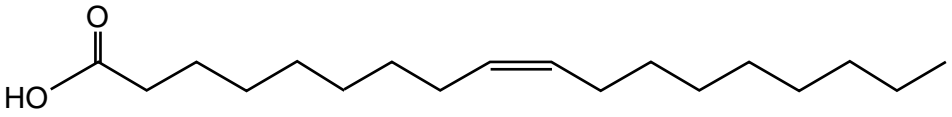
.....

..... [1]

(f) Another fatty acid that is believed to have beneficial health effects is oleic acid.



oleic acid

'Omega' is the last letter of the Greek alphabet. By comparing oleic acid, which is **not** an omega-3 fatty acid, with the omega-3 fatty acids on page 14, suggest what 'omega-3' relates to in the structure of these fatty acids.

.....

..... [1]

(g) Fatty acids can be converted to fatty acid methyl esters (FAMEs). These are the primary constituent of biodiesel. They also serve as 'green solvents' because FAMEs are biodegradable, produce low volatile components and are non-toxic to humans.

One method for conversion of fatty acids to FAMEs involves the reaction with diazomethane, $:\overset{-}{C}H_2\text{–}\overset{+}{N}\equiv N$, in an inert solvent.

$$RCO_2H + CH_2N_2 \rightarrow RCO_2CH_3 + N_2$$

The reaction of a fatty acid with diazomethane occurs via a two-step mechanism.

- In the first step, the fatty acid reacts with diazomethane to form a carboxylate ion intermediate.
- In the second step, N_2 is formed.

(i) Complete Figure 6.1 to suggest the mechanism for this reaction. Show any relevant lone pairs and dipoles, and indicate the movement of electron pairs with curly arrows.

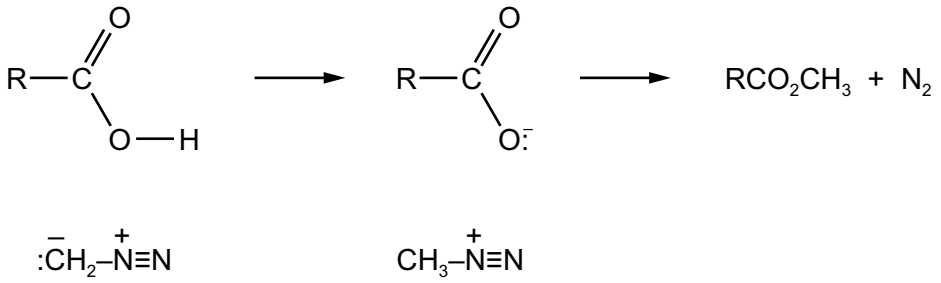


Figure 6.1

[4]

(ii) The conversion of fatty acids to FAMEs proceeds **very quickly** at **room temperature** and a **high yield** is obtained.

Suggest explanations for these observations in terms of:

- rate of reaction
- position of equilibrium.

.....

.....

.....

..... [2]

[Total: 13]

7 Table 7.1 shows some properties of five addition polymers and one condensation polymer.

Table 7.1

polymer	repeat unit	relative molecular mass of repeat unit	forces of attraction between chains	density / g cm^{-3}	tensile strength / N m^{-2}	melting point / °C
A	-[CH_2CH_2]-	28	id-id	0.92	15	110–130
B	-[CH_2CH_2]-	28	id-id	0.96	29	120–140
C	-[$CH(CH_3)CH_2$]-	42	id-id	0.90	35	176
D	-[$CH(C\mathit{l})$-CH_2]-	62.5	id-id & pd-pd	1.39	60	–
E	-[$NH(CH_2)_6NHCO(CH_2)_4CO$]-	226	id-id, pd-pd & H-bond	1.10	83	265
F	-[$CH_2CH=C(CH_3)CH_2$]-	68	id-id	0.93	32	–

Key: id-id = instantaneous dipole-induced dipole
pd-pd = permanent dipole-permanent dipole
H-bond = hydrogen bonding

Tensile strength is the maximum force that is applied to a material before it breaks.

(a) Draw a diagram to show the hydrogen bonding between two chains of polymer E. Show any relevant lone pairs and dipoles.

[2]

(b) Draw the structures of the two monomers used to produce the condensation polymer in Table 7.1.

[2]

(c) A student proposes hypothesis 1:

'The only factor that affects the tensile strength of a polymer is the molecular mass of its repeat unit.'

(i) Evaluate the information in Table 7.1 to explain why hypothesis 1 is false.

.....

.....

.....

..... [2]

(ii) Branched polymers are sometimes formed during the polymerisation process. The properties of branched polymers are different to the properties of linear polymers.

Using information about polymer A and polymer B in Table 7.1, suggest and explain the effect of branching in polymer chains on tensile strength of polymers.

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.....

.....

..... [2]

(d) Waste material can be removed by burning or deposited in sites known as landfill.

Suggest one problem associated with adding waste material that contains polymer E into landfill sites.

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..... [1]

[Total: 9]

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