



UNIVERSITY OF CAMBRIDGE INTERNATIONAL EXAMINATIONS
General Certificate of Education
Advanced Subsidiary Level and Advanced Level

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CHEMISTRY

9701/21

Paper 2 Structured Questions AS Core

May/June 2012

1 hour 15 minutes

Candidates answer on the Question Paper.

Additional Materials: Data Booklet

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

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- 1 Oxides are compounds which usually contain oxygen combined with one other element.

Oxides are classified as follows.

acidic

alkaline

amphoteric

basic

- (a) **Using these terms only**, complete the table to describe the oxides of the elements of the third period of the Periodic Table sodium to sulfur.

Na ₂ O	MgO	Al ₂ O ₃	SiO ₂	P ₄ O ₁₀	SO ₂	Cl ₂ O ₇
						acidic

[4]

- (b) Give the names of **two** elements from sodium to chlorine which form more than one oxide.

..... and

[1]

- (c) Sodium reacts with water.

- (i) Describe, as fully as you can, what you would see when a piece of sodium is reacted with water.

.....

- (ii) Write an equation for the reaction of sodium with water.

.....

[4]

(d) Sulfur dioxide is present in small, but significant, amounts in the Earth's atmosphere.

(i) State **one** way by which sulfur dioxide enters the atmosphere.

.....

(ii) Give the formula of another sulfur compound which is formed in the atmosphere from sulfur dioxide.

.....

(iii) What are the environmental consequences of the compound you have identified in (ii)?

.....

[3]

(e) Sulfur dioxide is used as a food preservative.

What property of sulfur dioxide enables it to act in this way?

..... [1]

(f) Another sulfur compound which is present in the Earth's atmosphere is carbonyl sulfide, OCS. The sequence of atoms in the molecule is oxygen-carbon-sulfur and the molecule is **not** cyclic.

(i) Draw a 'dot-and-cross' diagram of the OCS molecule.
Show outer electrons only.

(ii) Suggest a value for the O–C–S bond angle.

.....

[2]

[Total: 15]

- 2 Ammonium sulfate, $(\text{NH}_4)_2\text{SO}_4$, is widely used as a fertiliser.

In order to determine its percentage purity, a sample of ammonium sulfate fertiliser was analysed by reacting a known amount with an excess of $\text{NaOH}(\text{aq})$ and then titrating the unreacted NaOH with dilute HCl .

- (a) Ammonium sulfate reacts with NaOH in a 1 : 2 ratio.
Complete and balance the equation for this reaction.



[2]

- (b) A 5.00g sample of a fertiliser containing $(\text{NH}_4)_2\text{SO}_4$ was warmed with 50.0 cm^3 (an excess) of 2.00 mol dm^{-3} NaOH .

When all of the ammonia had been driven off, the solution was cooled.

The remaining NaOH was then titrated with 1.00 mol dm^{-3} HCl and 31.2 cm^3 were required for neutralisation.

- (i) Write a balanced equation for the reaction between NaOH and HCl .

.....

- (ii) Calculate the amount, in moles, of HCl in 31.2 cm^3 of 1.00 mol dm^{-3} HCl .

- (iii) Calculate the amount, in moles, of NaOH in 50.0 cm^3 of 2.00 mol dm^{-3} NaOH .

- (iv) Use your answers to (i), (ii) and (iii) to calculate the amount, in moles, of NaOH used up in the reaction with $(\text{NH}_4)_2\text{SO}_4$.

(v) Use your answer to (iv) and the equation in (a) to calculate the amount, in moles, of $(\text{NH}_4)_2\text{SO}_4$ that reacted with NaOH.

(vi) Use your answer to (v) to calculate the mass of $(\text{NH}_4)_2\text{SO}_4$ that reacted with NaOH.

(vii) Hence, calculate the percentage purity of the ammonium sulfate fertiliser.

[7]

[Total: 9]

- 3 Methanol, CH₃OH, is considered to be a possible alternative to fossil fuels, particularly for use in vehicles.

Methanol can be produced from fossil fuels and from agricultural waste. It can also be synthesised from carbon dioxide and hydrogen.

- (a) Define, with the aid of an equation which includes state symbols, the standard enthalpy change of formation of carbon dioxide.

equation

definition

.....

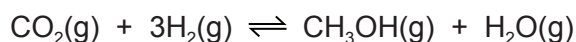
..... [3]

- (b) Relevant $\Delta H_f^\ominus$ values for the reaction that synthesises methanol are given in the table.

compound	$\Delta H_f^\ominus / \text{kJ mol}^{-1}$
CO ₂ (g)	–394
CH ₃ OH(g)	–201
H ₂ O(g)	–242

- (i) Use these values to calculate $\Delta H_{\text{reaction}}^\ominus$ for this synthesis of methanol.

Include a sign in your answer.



$$\Delta H_{\text{reaction}}^\ominus = \dots\dots\dots \text{kJ mol}^{-1}$$

- (ii) Suggest **one** possible environmental advantage of this reaction. Explain your answer.

.....

.....

[5]

- (c) The synthesis of methanol is carried out at about 500 K with a pressure of between 40 and 100 atmospheres (between 4×10^6 Pa and 10×10^7 Pa) and using a catalyst. The use of such conditions will affect both the rate of reaction and the equilibrium yield.

In the spaces below, explain the effects of higher temperature, higher pressure, and the use of a catalyst on the **equilibrium yield** of methanol.

higher temperature

effect

explanation

.....

higher pressure

effect

explanation

.....

use of catalyst

effect

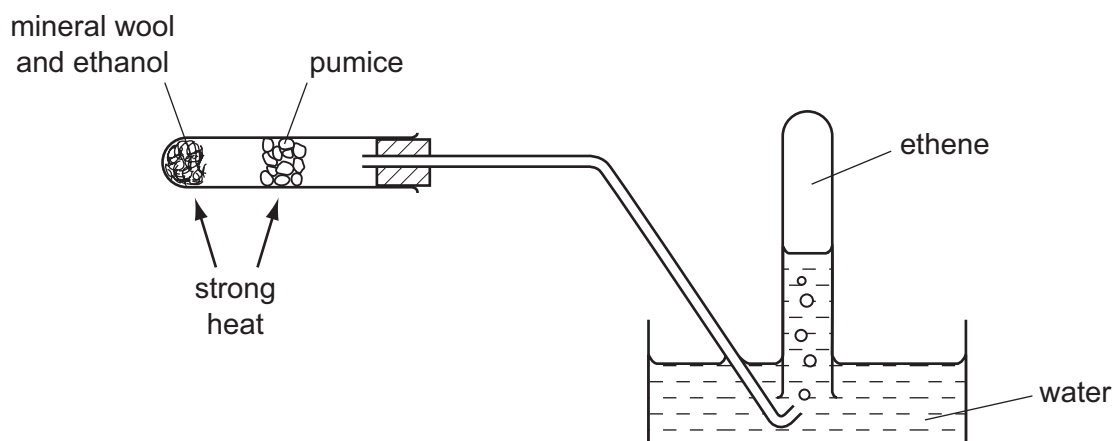
explanation

.....

[6]

[Total: 14]

- 4 One method of preparing ethene in a school or college laboratory is from ethanol by using the apparatus shown below.



- (a) (i) Write a balanced equation for this reaction.

.....

- (ii) What *type of reaction* is this?

.....

- (iii) Give the chemical name of a reagent other than pumice that could be used to carry out this reaction. It is not necessary to use the same apparatus.

.....

[3]

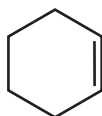
- (b) Ethene is bubbled into two separate test-tubes, one containing aqueous hydrogen bromide and the other containing cold, dilute acidified potassium manganate(VII).

In **each** case, describe any colour changes you would see and give the structural formula of the organic product.

	aqueous hydrogen bromide	cold, dilute acidified potassium manganate(VII)
colour at start		
colour after reaction		
structural formula of organic product		

[4]

(c) Cyclohexene has the following structural formula.



(i) What is the molecular formula of cyclohexene?

.....

(ii) Draw the structural formula of the compound formed when cyclohexene is reacted with bromine.

(iii) State as fully as you can what *type of reaction* this is.

.....

(iv) Draw the structural formula of the compound formed when cyclohexene is reacted with hot concentrated acidified potassium manganate(VII).

[5]

[Total: 12]

- 5 Organic compounds which contain oxygen may contain alcohol, aldehyde, carboxylic acid, ester or ketone functional groups. The functional groups may be identified by their reactions with specific reagents.

Compound **X** has the empirical formula CH_2O and M_r of 90.

- (a) There is no reaction when **X** is treated with NaHCO_3 .

What functional group does this test show to be **not** present in **X**?

.....

[1]

- (b) When 0.600 g of **X** is reacted with an excess of Na, 160 cm^3 of H_2 , measured at room temperature and pressure, is produced.

- (i) What functional group does this reaction show to be present in **X**?

.....

- (ii) Use the data to calculate the amount, in moles, of hydrogen **atoms** produced from 0.600 g of **X**.

- (iii) Hence, show that each molecule of **X** contains **two** of the functional groups you have given in (i).

[4]

(c) When **X** is warmed with Fehling's reagent, a brick red precipitate is formed.
Treatment of **X** with 2,4-dinitrophenylhydrazine reagent produces an orange solid.

(i) What functional group do these reactions show to be present in **X**?
Draw the displayed formula of this functional group.

(ii) Use your answers to (b)(i), (b)(ii) and (c)(i) to deduce the structural formula of **X**.

(iii) What is the structural formula of the organic product of the reaction of **X** with Fehling's reagent?

[3]

(d) Compound **X** can be both oxidised and reduced.

(i) Give the structural formula of the compound formed when **X** is reacted with NaBH_4 under suitable conditions.

(ii) Give the structural formula of the compound formed when **X** is heated under reflux with acidified $\text{K}_2\text{Cr}_2\text{O}_7$.

[2]

[Total: 10]

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- 1 The elements of the third period of the Periodic Table, sodium to sulfur, all form chlorides by direct combination.

(a) (i) Sulfur forms a number of chlorides which are liquid at room temperature.
Which other element of the third period forms a chloride which is liquid at room temperature?

.....

(ii) Name **one** element of the third period which burns in chlorine with a coloured flame.

.....

(iii) Aluminium chloride may be produced by passing a stream of chlorine over heated aluminium powder in a long hard-glass tube.
State **two** observations you could make during this reaction.

..... and

(iv) Write a balanced equation, with state symbols, for this reaction of aluminium with chlorine.

.....

(v) No chloride of argon has ever been produced.
Suggest a reason for this.

.....

.....

[7]

(b) When chlorides of the elements of the third period are added to water, some simply dissolve while others can be seen to react with the water.

(i) Complete the table below, stating how the chlorides of Na, Al, and Si behave when mixed with water. In the first column use only the terms 'dissolve' or 'react'.

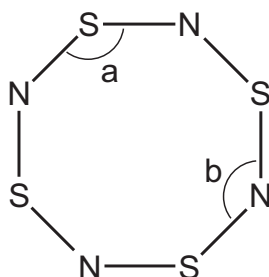
element	Does the chloride dissolve or react?	approximate pH of the resulting solution
Na		
Al		
Si		

(ii) What *type of reaction* takes place between a chloride and water?

.....

[7]

(c) Sulfur forms the compound S_4N_4 with nitrogen. The structure of S_4N_4 is shown below. Assume all bonds shown are single bonds.



(i) Determine the number of lone pairs of electrons around a nitrogen atom and a sulfur atom in S_4N_4 .

nitrogen atom

sulfur atom

(ii) Which bond angle, a or b, in the S_4N_4 molecule will be smaller? Explain your answer.

.....

.....

[2]

[Total: 16]

- 2 Alcohols such as methanol, CH_3OH , are considered to be possible replacements for fossil fuels because they can be used in car engines.

- (a) Define, with the aid of an equation which includes state symbols, the standard enthalpy change of combustion, $\Delta H_c^\ominus$, for methanol at 298 K.

equation

definition

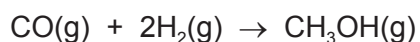
.....

..... [3]

Methanol may be synthesised from carbon monoxide and hydrogen. Relevant $\Delta H_c^\ominus$ values for this reaction are given in the table below.

compound	$\Delta H_c^\ominus / \text{kJ mol}^{-1}$
CO(g)	-283
$\text{H}_2\text{(g)}$	-286
$\text{CH}_3\text{OH(g)}$	-726

- (b) Use these values to calculate $\Delta H_{\text{reaction}}^\ominus$ for the synthesis of methanol, using the following equation. Include a sign in your answer.



$$\Delta H_{\text{reaction}}^\ominus = \dots\dots\dots \text{kJ mol}^{-1}$$

[3]

(c) The operating conditions for this reaction are as follows.

pressure 200 atmospheres (2×10^7 Pa)

temperature 600 K

catalyst oxides of Cr, Cu, and Zn

In the spaces below, explain how **each** of these conditions affects the **rate of formation** of methanol.

pressure

.....

.....

.....

temperature

.....

.....

.....

catalyst

.....

.....

.....

[6]

[Total: 12]

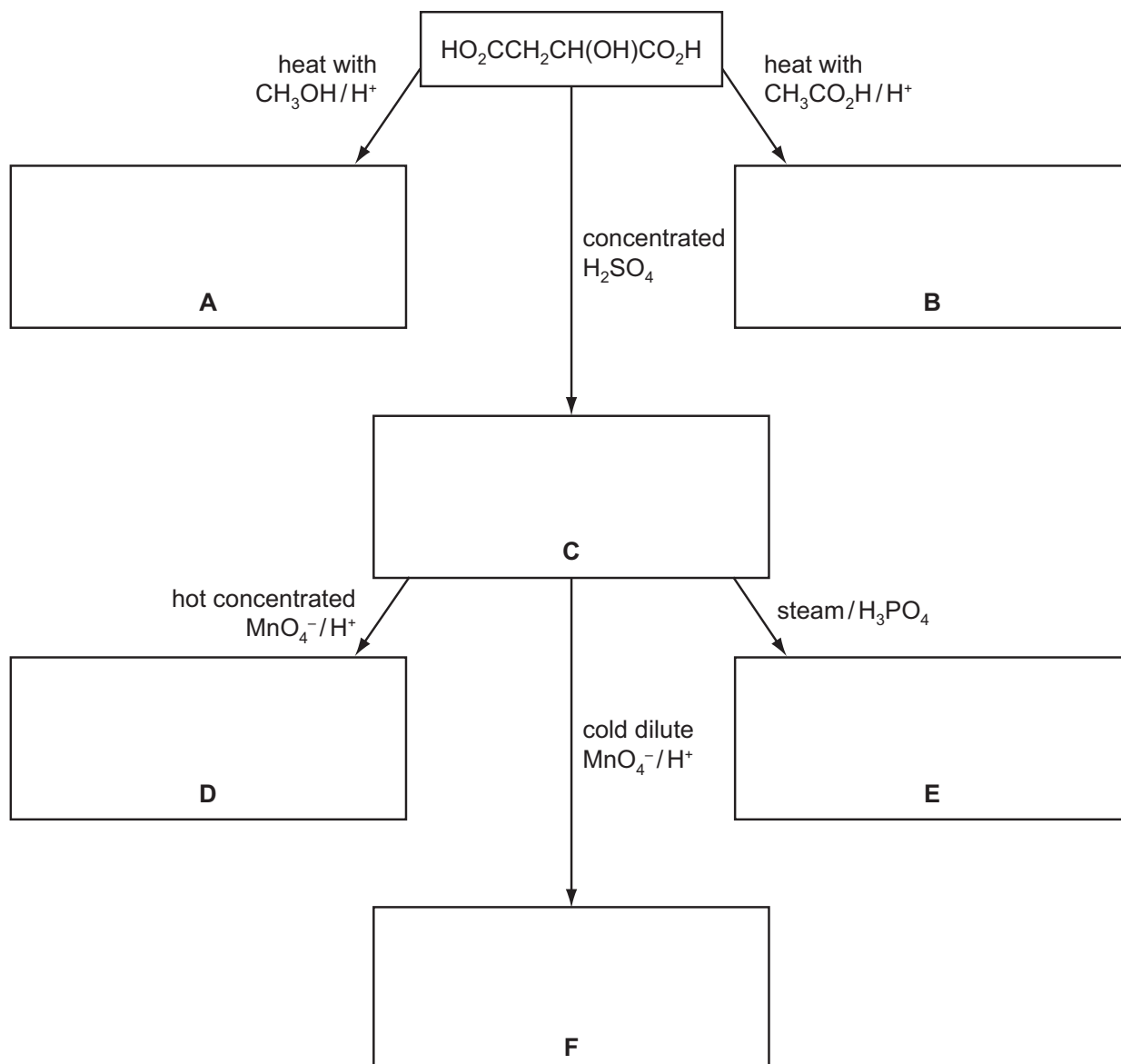
- 3 Food additives are substances added to food to preserve the flavour or to improve its taste and appearance.

European Union legislation requires most additives used in foods to be labelled clearly in the list of ingredients, either by name or by an 'E number'. E296 is malic acid which occurs in unripe fruit.

Malic acid has the structural formula $\text{HO}_2\text{CCH}_2\text{CH}(\text{OH})\text{CO}_2\text{H}$.

- (a) Some reactions of malic acid are shown below.

In the boxes below, give the **structural** formulae of organic compounds **A** to **F**.



[6]

(b) What *type of reaction* is **each** of the following conversions?

malic acid into **C**

C into **D**

C into **E**

[3]

(c) Suggest **one** major commercial use of compounds such as **A** or **B**.

..... [1]

(d) (i) Malic acid is chiral.

Draw fully displayed formulae of the two optical isomers of malic acid.

Indicate with an asterisk (*) the chiral carbon atom.

.....

(ii) Compound **C** also shows stereoisomerism.

Draw the skeletal formulae of **each** of the stereoisomers of **C**. Label **each** isomer.

[6]

(e) The food additive E330 is another organic compound which occurs naturally in fruit.

E330 has the following composition by mass: C, 37.5 %; H, 4.17 %; O, 58.3 %.

Calculate the empirical formula of E330.

[3]

[Total: 19]

- 4 Oxygen-containing organic compounds may contain a number of different functional groups including alcohol, aldehyde, carboxylic acid, ester or ketone functional groups. These functional groups may be identified by their reactions with specific reagents.

(a) On treating compounds containing each of these functional groups with the reagents below, only five reactions occur. Complete the table by placing a tick (✓) in each box where you believe a reaction will occur. You should place **no more** than five ticks in the table.

reagent	alcohol R_2CHOH	aldehyde $RCHO$	carboxylic acid RCO_2H	ester RCO_2R'	ketone $RCOR'$
$NaHCO_3$					
Na					
$Cr_2O_7^{2-}/H^+$					

[5]

Compound **G** has the empirical formula CH_2O and M_r of 90.

An aqueous solution of **G** is neutral. There is no reaction when **G** is treated with $NaHCO_3$.

When 0.30 g of pure **G** is reacted with an excess of Na, 80 cm³ of H_2 , measured at room temperature and pressure, is produced.

(b) (i) What functional group do these two reactions show to be present in **G**?

.....

(ii) Use the data to calculate the amount, in moles, of hydrogen **atoms** produced from 0.30 g of **G**.

(iii) Hence, show that each molecule of **G** contains **two** of the functional groups you have given in (i).

[4]

(c) Treatment of **G** with 2,4-dinitrophenylhydrazine reagent produces an orange solid. When **G** is warmed with Fehling's reagent, no reaction occurs.

(i) What functional group do these reactions show to be present in **G**?
Draw the displayed formula of this functional group.

(ii) Use your answers to (b)(i) and (c)(i) to deduce the structural formula of **G**.

[2]

(d) Compound **G** can be both oxidised and reduced.

(i) When **G** is heated under reflux with acidified $\text{K}_2\text{Cr}_2\text{O}_7$, compound **H** is formed.
Give the structural formula of compound **H**.

(ii) When **G** is reacted with NaBH_4 under suitable conditions, compound **J** is formed.
Give the structural formula of compound **J**.

[2]

[Total: 13]

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- 1 Although the actual size of an atom cannot be measured exactly, it is possible to measure the distance between the nuclei of two atoms. For example, the 'covalent radius' of the Cl atom is assumed to be half of the distance between the nuclei in a Cl_2 molecule. Similarly, the 'metallic radius' is half of the distance between two metal atoms in the crystal lattice of a metal. These two types of radius are generally known as 'atomic radii'.
The table below contains the resulting atomic radii for the elements of period three of the Periodic Table, Na to Cl .

element	Na	Mg	Al	Si	P	S	Cl
atomic radius/nm	0.186	0.160	0.143	0.117	0.110	0.104	0.099

- (a) (i) Explain qualitatively this variation in atomic radius.

.....

.....

.....

.....

.....

- (ii) Suggest why it is not possible to use the same type of measurement for argon, Ar.

.....

.....

[4]

- (b) (i) Use the *Data Booklet* to complete the following table of radii of the cations and anions formed by some of the period three elements.

radius of cation / nm			radius of anion / nm		
Na^+	Mg^{2+}	Al^{3+}	P^{3-}	S^{2-}	Cl^-

- (ii) Explain the differences in size between the cations and the corresponding atoms.

.....

.....

.....

- (iii) Explain the differences in size between the anions and the corresponding atoms.

.....

.....

.....

[5]

- (c) Each of the elements Na to Cl forms at least one oxide. Na_2O is an ionic oxide, SO_2 is a covalent oxide. Both oxides react with water.

- (i) Write an equation for the reaction of **each** of these oxides with water.

Na_2O

SO_2

- (ii) What is the pH of the resulting solution in **each** case?

Na_2O SO_2

- (iii) Write an equation for the reaction that occurs between the products of your reactions in (i).

.....

[5]

[Total: 14]

- 2 Washing soda is hydrated sodium carbonate, $\text{Na}_2\text{CO}_3 \cdot x\text{H}_2\text{O}$.

A student wished to determine the value of x by carrying out a titration, with the following results.

5.13 g of washing soda crystals were dissolved in water and the solution was made up to 250 cm^3 in a standard volumetric flask.

25.0 cm^3 of this solution reacted exactly with 35.8 cm^3 of $0.100 \text{ mol dm}^{-3}$ hydrochloric acid and carbon dioxide was produced.

- (a) (i) Write a balanced equation for the reaction between Na_2CO_3 and HCl .

.....

- (ii) Calculate the amount, in moles, of HCl in the 35.8 cm^3 of solution used in the titration.

- (iii) Use your answers to (i) and (ii) to calculate the amount, in moles, of Na_2CO_3 in the 25.0 cm^3 of solution used in the titration.

- (iv) Use your answer to (iii) to calculate the amount, in moles, of Na_2CO_3 in the 250 cm^3 of solution in the standard volumetric flask.

(v) Hence calculate the mass of Na_2CO_3 present in 5.13 g of washing soda crystals.

[6]

(b) Use your calculations in (a) to determine the value of x in $\text{Na}_2\text{CO}_3 \cdot x\text{H}_2\text{O}$.

[2]

[Total: 8]

- 3 With the prospect that fossil fuels will become increasingly scarce in the future, many compounds are being considered for use in internal combustion engines. One of these is DME or dimethyl ether, CH_3OCH_3 . DME is a gas which can be synthesised from methanol. Methanol can be obtained from biomass, such as plant waste from agriculture.

- (a) Define, with the aid of an equation which includes state symbols, the standard enthalpy change of combustion, $\Delta H_c^\ominus$, for DME at 298 K.

equation

definition

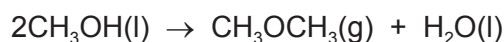
.....

..... [3]

- (b) DME may be synthesised from methanol. Relevant enthalpy changes of formation, $\Delta H_f^\ominus$, for this reaction are given in the table below.

compound	$\Delta H_f^\ominus / \text{kJ mol}^{-1}$
$\text{CH}_3\text{OH}(\text{l})$	−239
$\text{CH}_3\text{OCH}_3(\text{g})$	−184
$\text{H}_2\text{O}(\text{l})$	−286

Use these values to calculate $\Delta H_{\text{reaction}}^\ominus$ for the synthesis of DME, using the following equation. Include a sign in your answer.

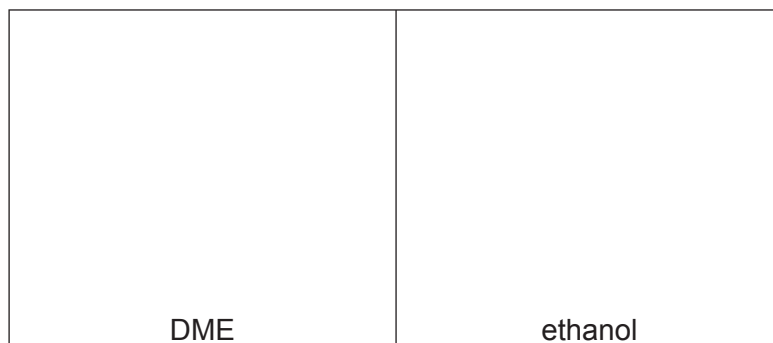


$$\Delta H_{\text{reaction}}^\ominus = \dots\dots\dots \text{kJ mol}^{-1}$$

[3]

(c) DME and ethanol are isomers with the molecular formula C_2H_6O .

(i) Draw the displayed formula of DME and of ethanol.



(ii) What type of isomerism do DME and ethanol show?

.....
[2]

(d) DME is a gas at room temperature while ethanol is a liquid.

(i) Which intermolecular force exists between ethanol molecules, which causes ethanol to be a liquid at room temperature?

.....

(ii) Draw a diagram that clearly shows this intermolecular force.
Your diagram should show any lone pairs or dipoles present that you consider to be important. You should represent at least two molecules in your diagram.

[4]

[Total: 12]

- 4 But-2-ene, $\text{CH}_3\text{CH}=\text{CHCH}_3$, is an important compound which is obtained from the cracking of hydrocarbons present in crude oil.

(a) Give **two** different conditions under which long chain hydrocarbons may be cracked.

.....

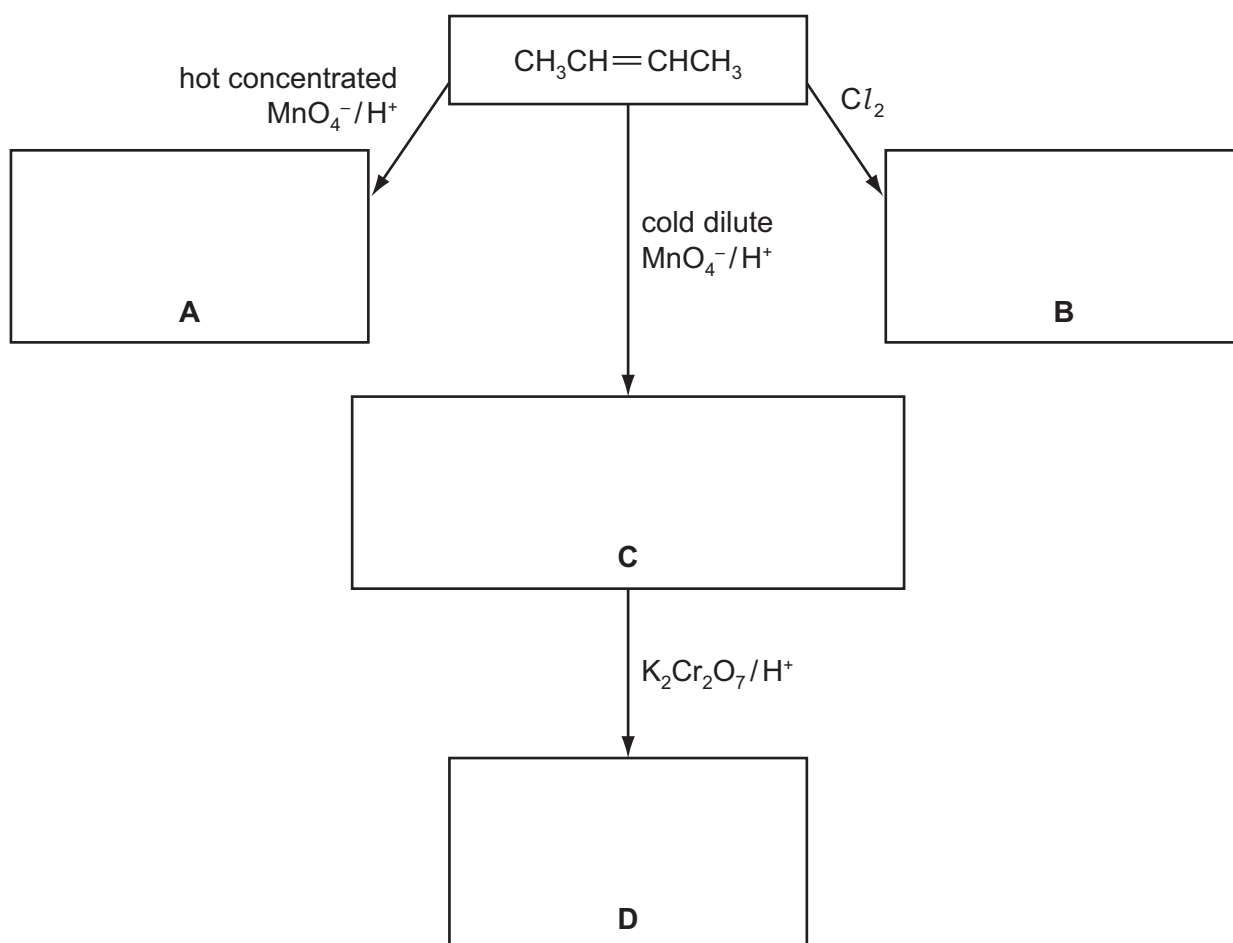
 [2]

- (b) Dodecane, $\text{C}_{12}\text{H}_{26}$, is a long chain hydrocarbon which is present in crude oil and which can be cracked to form but-2-ene and an alkane.

Write a balanced equation for this reaction.

..... [1]

- (c) Some reactions of but-2-ene are shown below.
 In the boxes below, give the **structural** formulae of the organic compounds **A** to **D**.



[4]

(d) (i) Draw the **skeletal** formula of compound **D**.

(ii) By using the letters **A** to **D** as appropriate, identify those compounds which are chiral. If there are none, write 'none'.

.....

[3]

(e) But-2-ene can be polymerised to give poly(butene).

Draw the **structural** formula of a portion of the polymer chain in poly(butene) showing **two** repeat units.

[1]

(f) Compound **C** is a liquid which can be reacted with concentrated sulfuric acid to give a gas, **E**, which will decolourise aqueous bromine when passed through it.

(i) Suggest the **structural** formula of **E**.

(ii) Suggest the **structural** formula of the product of the reaction between **E** and an excess of bromine.

(iii) What *type of reaction* occurs between **E** and an excess of bromine?

.....

[3]

[Total: 14]

- 5 Many naturally occurring organic compounds contain oxygen. Such compounds may contain alcohol, aldehyde, carboxylic acid, ester or ketone functional groups. These functional groups may be identified by their reactions with specific reagents.

Compound **F** is a white solid which has the molecular formula $C_3H_6O_3$.

Compound **F** is soluble in water. Addition of $NaHCO_3$ to this solution produces a colourless gas, **G**, which turns lime water milky.

- (a) (i) What is the identity of the gas **G**?

.....

- (ii) What functional group does this test show to be present in **F**?

.....

[2]

- (b) When **F** is heated with concentrated sulfuric acid, a colourless liquid **H** is produced. When cold dilute acidified $KMnO_4$ is shaken with **H**, the solution becomes colourless.

- (i) What *type of reaction* occurs when **H** is formed from **F**?

.....

- (ii) Use your answers to (a)(ii) and (b)(i) to deduce the structural formula of the colourless liquid **H**.

[4]

(c) Compound **F** will react with sodium.

Calculate the volume of H_2 , measured at room temperature and pressure, which will be produced when 0.600 g of **F** is reacted with an excess of Na.

[4]

(d) There are two structural isomers of **F** that give the reactions described in (a) and (b).

(i) Suggest two structural formulae for these isomers.

J	K
----------	----------

(ii) Isomers **J** and **K** can both be oxidised.
What will be produced when **each** of the isomers **J** and **K** is heated under reflux with acidified $\text{K}_2\text{Cr}_2\text{O}_7$?

product from J	product from K
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[2]

[Total: 12]

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