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Principal: Mrs O. Tomlinson

OCR CHEMISTRY A

AS LEVEL

UNIT 2 MORE PAST PAPER QUESTIONS

Includes some questions on acids from Unit 1

Boa sorte!

mark schemes available at

www.a-levelchemistry.co.uk

For Examiner's Use

1 The table below shows information about some alcohols which form part of an homologous series.

name	formula	boiling point / °C	relative molecular mass
methanol	CH_3OH	65	32
ethanol	C_2H_5OH	78	46
propan-1-ol	C_3H_7OH	97	60
butan-1-ol	C_4H_9OH		74
pentan-1-ol	$C_5H_{11}OH$	138	
hexan-1-ol	$C_6H_{13}OH$	158	102

(a) (i) Identify the functional group common to all alcohols. ..... [1]

(ii) What is the general formula for these alcohols? ..... [1]

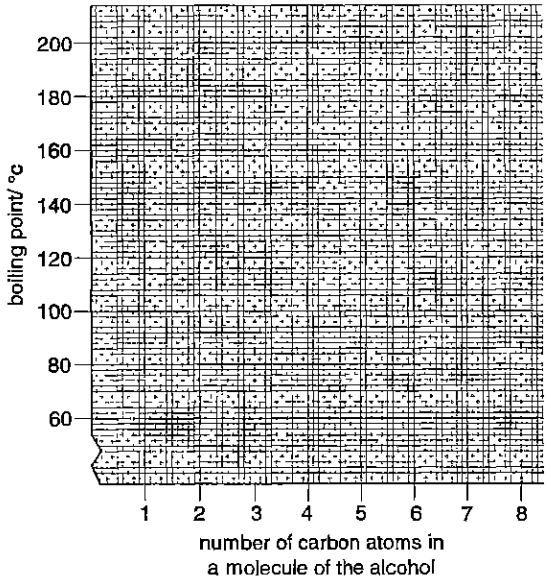
(iii) What is the formula of the next alcohol in the series? ..... [1]

(b) Calculate the relative molecular mass of pentan-1-ol.

[1]

For Examiner's Use

(c) (i) Plot a graph of boiling point against number of carbon atoms in a molecule of the alcohol.



[2]

Use the graph to estimate the boiling points of

butan-1-ol, ... [1]

$C_8H_{17}OH$. ..... [1]

(ii) State the connection between boiling point and the relative molecular mass of these alcohols.

.....

..... [1]

[Total: 9]

[Turn over

2 The hydrocarbons in crude oil can be separated by fractional distillation.

(a) Explain what is meant by the terms

(i) *hydrocarbons,* .....

..... [1]

(ii) *fractional distillation.* .....

.....

..... [1]

(b) Undecane, $C_{11}H_{24}$, can be isolated by fractional distillation.

Calculate the percentage composition by mass of carbon in undecane.

[3]

(c) Undecane can be cracked into nonane and compound **A**. One molecule of nonane contains nine carbon atoms.

(i) Write a balanced equation for this reaction.

..... [2]

(ii) Name compound **A**.

..... [1]

(d) Hydrocarbons of formula C_5H_{12}, can also be isolated from crude oil.

(i) Draw the three structural isomers of C_5H_{12}.

Isomer **B**	Isomer **C**	Isomer **D**

[3]

(ii) Isomers, **B**, **C** and **D** can be separated by fractional distillation. State the order, lowest boiling point first, in which they would distil.

..... [1]

(iii) Justify the order stated in **(d)(ii)**.

.....

..... [1]

(iv) Write a balanced equation for the **complete** combustion of pentane, C_5H_{12}.

..... [2]

(v) Why do oil companies isomerise alkanes such as pentane?

.....

..... [1]

[Total: 16]

For Examiner's Use

3 Propane, C_3H_8, reacts with Cl_2 in the presence of sunlight to form a mixture of chlorinated products. One possible product is C_3H_7Cl, formed as shown in the following equation.

$$C_3H_8 + Cl_2 \rightarrow C_3H_7Cl + HCl$$

(a) Describe, with the aid of equations, the mechanism of this reaction.

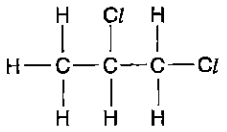
initiation .....

propagation .....

.....

termination ..... [4]

(b) One other possible product of the reaction between propane and chlorine is compound **H**, shown below.



compound **H**

(i) Name compound **H**. ..... [1]

(ii) Draw **two other** structural isomers of $C_3H_6Cl_2$.

[2]

(c) 1-Chloropropane can react with a solution of sodium hydroxide as shown in the equation below.

$$C_3H_7Cl + OH^- \rightarrow C_3H_7OH + Cl^-$$

(i) State the solvent in which the sodium hydroxide is dissolved.

..... [1]

(ii) State and explain the role of the hydroxide ion, OH^-, in this reaction.

.....

..... [2]

For Exam Us

(d) Propan-1-ol, C_3H_7OH, is refluxed with an acidified solution of potassium dichromate(VI) to produce propanoic acid. The acidified potassium dichromate(VI) acts as an oxidising agent.

(i) Explain what is meant by the term *reflux*.

.....

..... [1]

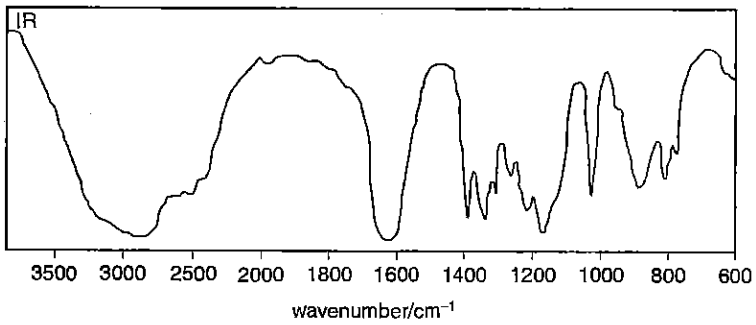
(ii) State what colour change takes place in the reaction mixture.

from ..... *to* ..... [2]

(iii) Write a balanced equation for the oxidation of propan-1-ol to propanoic acid. The oxidising agent can be represented as [O] in your equation.

..... [2]

(e) An infra-red spectrum of propanoic acid was obtained. By referring to your *Data Sheet*, identify two peaks in the infra-red spectrum that confirm the presence of the carboxylic acid functional group.



Peak 1 wavenumber/cm^{-1} .....

bond .....

Peak 2 wavenumber/cm^{-1} .....

bond .....

[4]

[Total: 19]

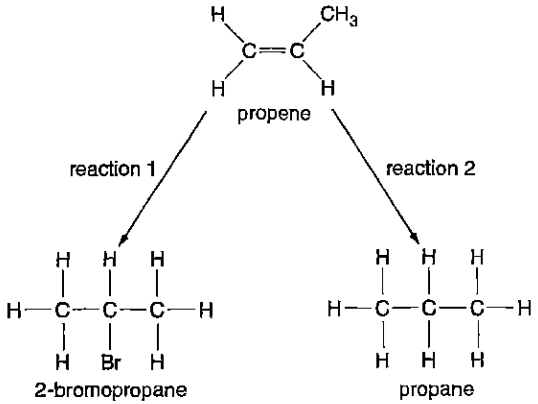
[Turn over

For Examiner Use

4 **(a)** Propene, C_3H_6, readily undergoes electrophilic addition reactions. Show, with the aid of curly arrows, the mechanism of the electrophilic addition reaction of propene with bromine.

[4]

(b) Propene also reacts as shown below.



(i) State a suitable reagent for reaction 1.

..... [1]

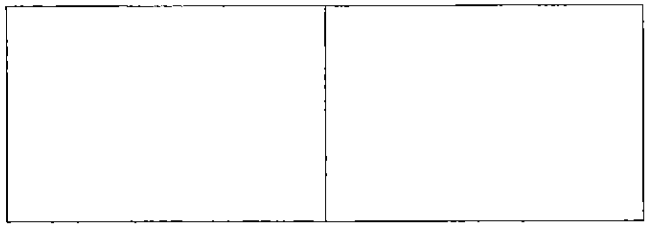
(ii) State a suitable reagent and conditions for reaction 2.

.....

..... [2]

For Examiner Use

(iii) In the presence of an acid catalyst, propene can react with steam to form a mixture of two alcohols. Draw the structures of the two alcohols.



[2]

(c) The scientists Ziegler and Natta were awarded a Nobel Prize for chemistry in 1963 for their work on polymerisation. Part of this work involved the polymerisation of propene into poly(propene).

(i) What type of polymerisation forms poly(propene)?

..... [1]

(ii) Draw a section of poly(propene) to show **two** repeat units.

[1]

(iii) State **two** difficulties in the disposal of poly(propene).

.....

.....

..... [2]

[Total: 13]

[Turn over

5 Alcohols can be converted into chloroalkanes by reaction with hydrochloric acid, HCl.

2-Chloro-2-methylpropane can be prepared by shaking together 5.1 cm^3 (4.0 g) of 2-methylpropan-2-ol with 20 cm^3 of concentrated HCl. After 10 minutes two separate layers begin to form.

(a) (i) What is the molecular formula of 2-methylpropan-2-ol, $(CH_3)_3COH$?

..... **[1]**

(ii) Write a balanced equation for the reaction between 2-methylpropan-2-ol and HCl.

..... [1]

Use the data in the table below to answer the questions that follow.

compound	relative molecular mass	density / g cm^{-3}	boiling point / °C
2-methylpropan-2-ol	74	0.78	83
2-chloro-2-methylpropane	92.5	0.84	51
water	18	1.00	100

One of the layers is aqueous and the other contains the organic product.

(b) Suggest whether the upper or lower layer is likely to contain the organic product.

Explain your reasoning.

.....

..... **[1]**

(c) *The organic layer was shaken with a dilute solution of sodium hydrogencarbonate, $NaHCO_3$. A gas was given off.*

Identify the gas that was given off. ..... [1]

Suggest the chemical that could have reacted with the $NaHCO_3$ to form the gas.

..... **[1]**

(d) *The resulting impure organic liquid was dried with anhydrous calcium chloride and then distilled. 3.75g of pure 2-chloro-2-methylpropane was produced.*

(i) At what temperature would you expect the **pure** organic product to distil?

..... [1]

(ii) Calculate how many moles of 2-methylpropan-2-ol were used in the experiment.

[1]

(iii) Calculate how many moles of pure 2-chloro-2-methylpropane were produced.

[1]

(iv) Calculate the percentage yield of 2-chloro-2-methylpropane in this experiment.

[1]

[Total: 9]

For Examiner Use

6 The production of body odour often begins with secretions from glands called apocrine glands which are most numerous in the armpits. Skin bacteria, which live in the armpits, use these secretions to produce energy and many different waste products. Scientists have isolated one of these products, compound **E**, which is shown below. Compound **E** can be oxidised to form compounds **F** and **G**.

Compound **E** Compound **G**

(a) Compound **E** contains two functional groups. Identify both functional groups and state how you could test for each.

functional group 1 .....

test .....

observation .....

functional group 2 .....

test .....

observation .....

[6]

(b) Suggest the structural formula of compound **F**.

[1]

[Total: 7]

For Examiner Use

7 **There are two different industrial methods** for the production of ethanol. Describe and explain, with the aid of equations, the industrial production of ethanol from glucose and from ethene.

(In this question, 1 mark is available for the quality of written communication.)

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[Total: 9]

For Examiner Use

8 Describe, with the aid of suitable diagrams, the bonding in ethane and in ethene. State the shape, and an approximate value for the bond angles, around each carbon atom.

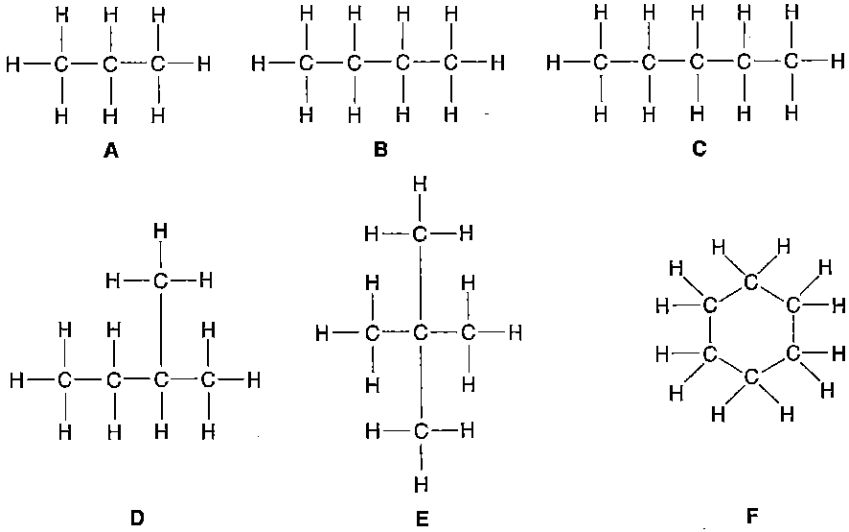
(In this question, 1 mark is available for the quality of written communication.)

[Total: 8]

For Examiner Use

1 The structures of some saturated hydrocarbon compounds are shown below.

They are labelled **A**, **B**, **C**, **D**, **E** and **F**.



A **B** **C** **D** **E** **F**

(a) The general formula of an alkane is C_nH_{2n+2}.

(i) Which of the compounds, **A** to **F**, has a formula that does **not** fit with this general formula?

..... [1]

(ii) **A**, **B**, and **C** are successive members of the alkane series.

What is the **molecular** formula of the next member in the series?

..... [1]

(iii) What is the **empirical** formula of compound **F**?

..... [1]

(b) Three of compounds **A** to **F** are structural isomers of each other.

(i) Identify, by letter, which of the compounds are the three structural isomers.

....., ..., and ..... . [1]

(ii) Explain what is meant by the term *structural isomer*.

..... [1]

(c) (i) Which of the compounds, **A**, **B** or **C**, would you expect to have the highest boiling point?

..... [1]

(ii) Which of the compounds, **C**, **D** or **E**, would you expect to have the highest boiling point?

..... [1]

(iii) Explain your answers to **(c)(i)** and **(c)(ii)** in terms of intermolecular forces.

.....

.....

.....

..... [3]

[Total: 10]

[Turn over

2 An alcohol, **G**, has a relative molecular mass of 74 and has the following composition by mass: C, 64.9%; H, 13.5%; O, 21.6%.

(a) (i) Show that the empirical formula of **G** is $C_4H_{10}O$.

[2]

(ii) Show that the molecular formula of **G** is the same as its empirical formula.

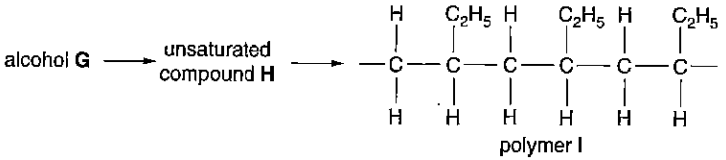
[1]

(b) There are four structural isomers of $C_4H_{10}O$ that are alcohols. Alcohols can be classified as primary, secondary or tertiary. Complete the table below.

structural isomer	formula	name	classification
1	$CH_3—CH_2—CH_2—CH_2—OH$	butan-1-ol	
2			secondary
3	$H_3C—\underset{\displaystyle CH_3}{\overset{\displaystyle |}{CH}}—CH_2—OH$		
4		2-methylpropan-2-ol	

[7]

(c) The alcohol **G** can be dehydrated to form an unsaturated compound **H** which can be polymerised to give polymer **I**.



(i) Explain what is meant by the term *unsaturated*.

.....

..... [1]

(ii) Describe a simple chemical test to show unsaturation.

test .....

observation ..... [2]

(iii) Circle the repeat unit of polymer **I** in the diagram above. [1]

(iv) Identify the unsaturated compound **H** and draw its structure.

[1]

(v) Suggest an identity of alcohol **G**.

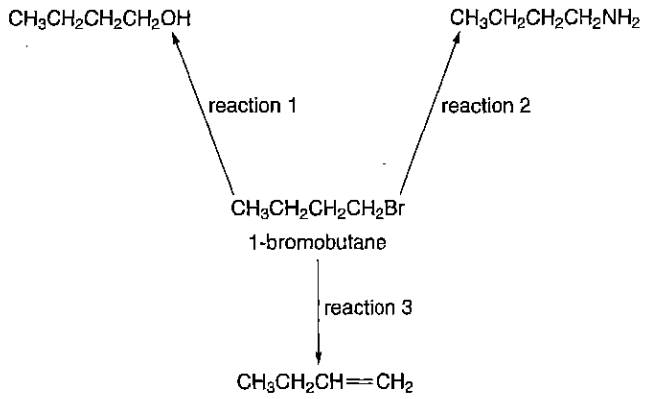
[1]

(vi) Draw the **skeletal** formula of the alcohol **G**.

[1]

[Total: 17]

3 Some reactions of 1-bromobutane, $CH_3CH_2CH_2CH_2Br$, are shown below.



(a) For each of the reactions shown, name the reagent and the solvent used.

reaction 1

reagent .....

solvent .....

reaction 2

reagent .....

solvent .....

reaction 3

reagent .....

solvent .....[6]

(b) Under the same conditions, 1-chlorobutane was used in reaction 1 in place of 1-bromobutane.

What difference (if any) would you expect in the rate of reaction? Explain your answer.

.....

.....

..... [2]

(c) Dichlorodifluoromethane, CCl_2F_2, is an example of a chlorofluorocarbon, CFC, that was commonly used as a propellant in aerosols. Nowadays CFCs have limited use because of the damage caused to the ozone layer.

(i) Draw a diagram to show the shape of a molecule of CCl_2F_2.

[1]

(ii) Predict an approximate value for the bond angles in a molecule of CCl_2F_2.

..... [1]

(iii) Suggest a property that makes CCl_2F_2 suitable as a propellant in an aerosol.

..... [1]

(iv) When CFCs are exposed to strong ultraviolet radiation in the upper atmosphere, homolytic fission takes place to produce free radicals.

Explain what is meant by the term *homolytic fission.*

..... [1]

(v) Suggest which bond is most likely to be broken when CCl_2F_2 is exposed to ultraviolet light. Explain your answer.

bond .....

reason .....

..... [2]

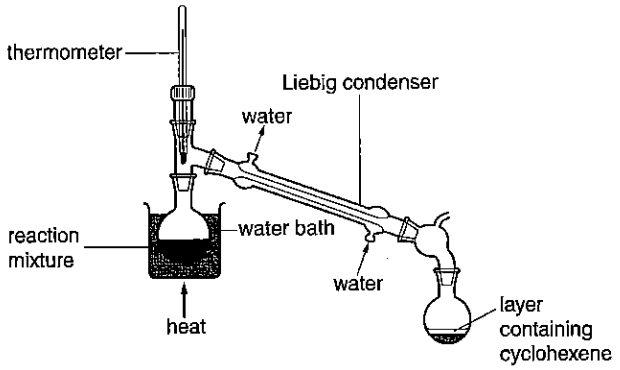
(vi) Identify **two** free radicals most likely to be formed when CCl_2F_2 is exposed to ultraviolet light.

..... and ..... [2]

[Total :16]

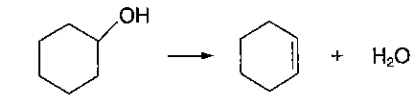
4 Cyclohexene, C_6H_{10}, can be prepared from cyclohexanol, $C_6H_{11}OH$, by the dehydration method described below.

A reaction mixture of 10.0 g cyclohexanol and 4 cm^3 of phosphoric acid, H_3PO_4, was placed in a round-bottomed flask and the apparatus arranged as shown below. An impure liquid, consisting of two immiscible layers, was collected after distillation.



The upper organic layer was separated and dried. Finally it was re-distilled to yield 3.69 g of cyclohexene.

The equation for the preparation can be represented as either



or

$C_6H_{11}OH \longrightarrow C_6H_{10} + H_2O$

Use the information above to answer the questions that follow.

(a) Suggest an impurity that could have been in the mixture after the first distillation.

..... [1]

(b) (i) What is the relative molecular mass of cyclohexanol?

..... [1]

(ii) How many moles of cyclohexanol were used in the experiment?

[1]

(iii) How many moles of cyclohexene were produced in the experiment?

[2]

(iv) Calculate the percentage yield of cyclohexene in the experiment.

[2]

(c) Suggest how infra-red spectroscopy could be used to show that the product was not contaminated with any unreacted cyclohexanol. Refer to the *Data Sheet* in your answer.

.....

.....

.....

.....

..... [2]

[Total: 9]

5 Reagents used in organic chemistry may contain electrophiles, nucleophiles or free radicals.

In the spaces below:
explain what is meant by each term;
give an example of each type of species;
write a balanced equation for a reaction that involves each species.

(a) (i) *electrophile* .....

..... [1]

(ii) *example* ..... [1]

(iii) Write a balanced equation to illustrate electrophilic addition.

..... [1]

(b) (i) *nucleophile* .....

..... [1]

(ii) *example* ..... [1]

(iii) Write a balanced equation to illustrate nucleophilic substitution.

..... [1]

(c) (i) *free radical* .....

..... [1]

(ii) *example* ..... [1]

(iii) Write a balanced equation to illustrate free-radical substitution.

..... [1]

[Total: 9]

6 Many drinks have a characteristic smell. 2-Ethyl-3-methylbutanoic acid, $C_7H_{14}O_2$, gives rum its characteristic aroma.

(a) 2-Ethyl-3-methylbutanoic acid can be prepared in the laboratory by oxidation of 2-ethyl-3-methylbutan-1-ol, $(CH_3)_2CHCH(C_2H_5)CH_2OH$.

(i) State the reagents and conditions that could be used for this oxidation. Describe what colour change you would see.

reagents .....

conditions .....

colour change from ..... *to* ..... . [4]

(ii) State, with a reason, whether a reflux apparatus or a distillation apparatus should be used to produce the correct oxidation product.

.....

.....

..... [2]

(iii) What is the molecular formula of 2-ethyl-3-methylbutan-1-ol? ..... [1]

(iv) Using [O] to represent the oxidising agent, write a balanced equation for this oxidation.

..... [2]

(v) Identify a likely organic impurity which could be formed in this oxidation.

..... [1]

(b) If 2-ethyl-3-methylbutan-1-ol were replaced by 2-ethyl-3-methylbutan-2-ol, oxidation would **not** occur in this experiment. Explain why not.

.....

..... [2]

[Total: 12]

[Turn over

(In this question, 1 mark is available for the quality of written communication.)

7 Describe and explain how ethene reacts with bromine. You should include in your answer:

- any observations,
- the name of the organic product,
- a full description of the mechanism.

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[Total: 7]

(In this question, 1 mark is available for the quality of written communication.)

8 The fractions from crude oil can be processed further by either cracking, reforming or isomerisation.

Outline, with the aid of suitable examples and equations, each of these processes.

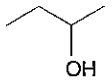
State clearly the industrial importance of each process.

[Total: 10]

Answer **all** the questions.

1 **(a)** State the name of

(i) $CH_3CH_2CH_2OH$ .....[1]

(ii) 

.....[1]

(b) What is the molecular formula of $(CH_3)_2CHCH(CH_3)_2$? .....[1]

(c) What is the empirical formula of $(CH_3)_2CHCH(CH_3)_2$? .....[1]

(d) To which homologous series does $(CH_3)_2CHCH(CH_3)_2$ belong? .....[1]

(e) Show the structural formula of a primary, a secondary and a tertiary isomer of C_4H_9Cl.

primary	secondary	tertiary

[3]

[Total : 8]

For Examiner's Use

2 **(a)** When chlorine, Cl_2, reacts with methane or with ethene the C*l*–C*l* bond undergoes fission. The bond fission occurs by a **different** process in each reaction.

(i) Explain what is meant by the term *bond fission.*

.....

.....[1]

(ii) State the type of fission of the C*l*–C*l* bond in the reaction between Cl_2 and

methane, ...

ethene. .....[2]

(iii) Write a balanced equation to illustrate **each** type of fission of the C*l*–C*l* bond.

.....

.....[2]

(b) The products formed by fission of the C*l*–C*l* bond can then react with a range of organic chemicals. Identify the product of C*l*–C*l* bond fission that could behave as:

a nucleophile, ...

an electrophile, ...

a free radical. .....[3]

[Total : 8]

For Examiner's Use

3 The table below gives the names and molecular formulae of some alkanes present in crude oil.

name	molecular formula
methane	CH_4
ethane	C_2H_6
propane	C_3H_8
hexane	C_6H_{14}
octane	C_8H_{18}
decane	$C_{10}H_{22}$
octadecane	$C_{18}H_{38}$

(a) **(i)** What is the general formula of the alkanes? .....[1]

(ii) What is the difference in formulae between successive members of the alkanes?

.....[1]

(iii) Suggest the molecular formula of the alkane *hexadecane*? .....[1]

(b) **(i)** Explain why the cracking of long-chain alkanes such as octadecane is important.

.....

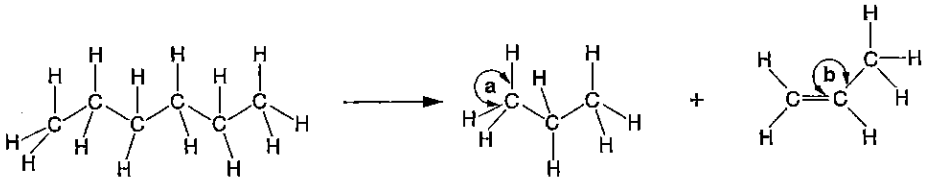
.....

.....[2]

(ii) Under certain conditions octadecane, $C_{18}H_{38}$, can be cracked into hexane and an alkene. What is the molecular formula of the alkene?

.....[1]

(c) Hexane can be cracked further into propane and propene as shown below.



hexane propane propene

(i) Predict the value of

bond angle '**a**' in propane ..... and bond angle '**b**' in propene .....[2]

For Examiner's Use

(ii) Propene is unsaturated and contains a π-bond. Explain, with the aid of a diagram, how p-orbitals are involved in the formation of the π-bond in propene.

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.....[2]

(iii) Describe how propane and propene could be distinguished by a simple chemical test.

.....

.....

.....[2]

(d) A major commercial use of propene is the production of the polymer poly(propene).

(i) Draw a section of poly(propene) showing **two** repeat units.

[2]

(ii) State the type of polymerisation .....[1]

(e) Hydrocarbon polymers such as poly(propene) can be disposed of by using land-fill sites or by burning in an incinerator.

(i) State **one** disadvantage of disposal in a land-fill site.

.....[1]

(ii) State **one** possible advantage and **one** disadvantage if they are disposed of by burning.

advantage .....

.....

disadvantage .....

.....[2]

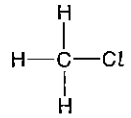
[Total : 18]

[Turn over

For Examiner's Use

4 Halogenoalkanes are polar molecules and react with nucleophiles.

(a) The displayed formula of chloromethane is shown below. Label the dipole on the C–Cl bond.



[1]

(b) Chloromethane is hydrolysed by aqueous sodium hydroxide in a nucleophilic substitution reaction. An equation for this reaction is shown below.

$$CH_3Cl + OH^- \longrightarrow CH_3OH + Cl^-$$

(i) What is meant by the term *nucleophile*?

.....

.....[1]

(ii) Show, with the aid of curly arrows, the mechanism of this hydrolysis.

[2]

(c) **(i)** What would happen to the rate of hydrolysis if chloromethane were replaced by iodomethane? Explain your answer.

.....

.....

.....[2]

(ii) Suggest a reagent that could be used to compare the rate of the hydrolysis of both halogenoalkanes. State what you would see in each case.

reagent .....

observation(s) with chloromethane .....

.....

observation(s) with iodomethane .....

.....[5]

For Examiner's Use

(d) Compound **D** has the following composition by mass: C, 12.76%; H, 2.13%; Br, 85.11%.

(i) Calculate the empirical formula of **D**. Show your working.

[2]

(ii) Compound **D** has a relative molecular mass of 187.8.

What is the molecular formula of **D**? Show your working.

[2]

(iii) Identify **two** possible structural isomers of **D**.

[2]

(e) Complete hydrolysis of **D** forms ethane-1,2-diol, which is used as anti-freeze in cars.

(i) Draw the displayed formula of ethane-1,2-diol.

[1]

(ii) Which of the isomers in **(d)(iii)** is **D**. Explain your answer.

[1]

(iii) Write a balanced equation for the complete hydrolysis of **D**.

.....[2]

(iv) Suggest why ethane-1,2-diol is suitable for use as *anti-freeze*.

.....

.....[1]

[Total : 22]

For Examiner's Use

5 Alcohols can react with carboxylic acids to produce esters. Esters are often described as having 'fruity smells'.

The following experiment was carried out to produce the ester, $CH_3COOCH_2CH_2CH(CH_3)_2$, which contributes to the flavour of ripe pears.

An 8.8 g sample of 3-methylbutan-1-ol, $(CH_3)_2CHCH_2CH_2OH$, and 6.0 g of ethanoic acid, CH_3COOH, were mixed in a flask and 2.0 g of concentrated sulphuric acid were added. The mixture was refluxed for four hours and then fractionally distilled to give the crude ester. The ester was washed repeatedly with aqueous sodium carbonate, to remove any acid present, until there was no more effervescence. The mixture was distilled and 7.8 g of ***pure*** *ester were obtained.*

(a) By referring to the experimental procedure above,

(i) state the role of the concentrated sulphuric acid,

.....[1]

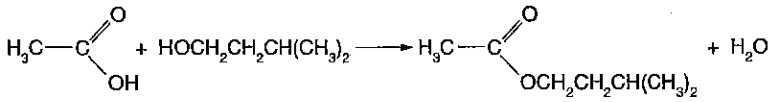
(ii) explain the meaning of *refluxed*, ...

.....[1]

(iii) suggest which gas was responsible for the *effervescence*.

.....[1]

(b) The equation for the esterification is given below.



(i) Calculate the relative molecular mass of CH_3COOH.

Answer .....[1]

(ii) Calculate how many moles of CH_3COOH were used.

Answer .....[1]

For Examiner's Use

(iii) Deduce the theoretical yield, in moles, of the ester $CH_3COOCH_2CH_2CH(CH_3)_2$.

Answer .....[1]

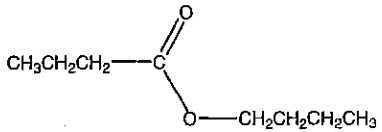
(iv) The student produced 7.8 g of the **pure** ester, $CH_3COOCH_2CH_2CH(CH_3)_2$ ($M_r = 130$). Calculate how many moles of **pure** ester were produced in this experiment.

Answer .....[1]

(v) Calculate the percentage yield of **pure** ester obtained in this experiment.

Answer .....[1]

(c) Butan-1-ol, $CH_3CH_2CH_2CH_2OH$, reacts with a carboxylic acid to produce ester, **E**, which is found in pineapples.



E

(i) Draw the displayed formula of butan-1-ol.

[1]

(ii) Draw the structure of the carboxylic acid used to produce **E**.

[1]

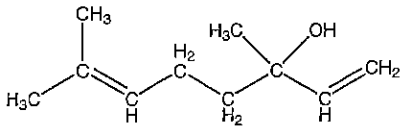
(iii) Write a balanced equation for the formation of **E** from butan-1-ol.

[1]

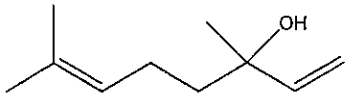
[Total : 11]

For Examiner's Use

6 The structure of linalool, $C_{10}H_{18}O$, which occurs naturally in rose oil, is shown below.



structural formula



skeletal formula

(a) Identify the **two different** functional groups present in linalool.

..... and ..... [2]

(b) Linalool reacts with hydrogen in the presence of a catalyst. A fully saturated compound, **A**, is produced.

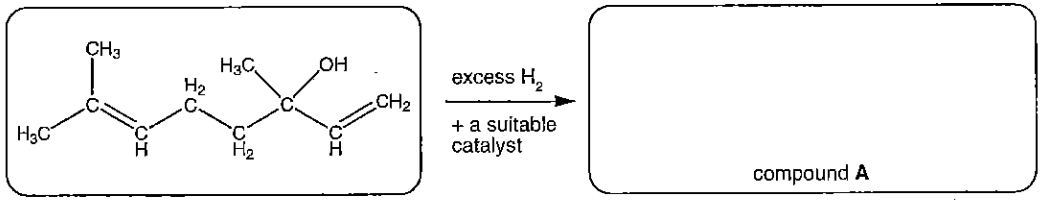
(i) Explain what is meant by the term *saturated*.

.....

.....[1]

(ii) Suggest a suitable catalyst for this reaction. .....[1]

(iii) Complete the reaction scheme below.



[2]

(iv) Draw the skeletal formula of **A**.

[1]

[Total : 7]

For Examiner Use

7 **(a)** Explain what is meant by the terms *structural isomerism* and *cis-trans isomerism*. In your answer refer to isomers of C_4H_8 **only**. Clearly identify by formula and by name each isomer and state the key feature required for each type of isomerism.

(In this question, 2 marks are available for the quality of written communication)

.....[11]

Question 7 part (b) overleaf

For Examiner's Use

Question 7 continued.

(b) Under certain conditions alkenes such as propene can react to form alcohols. State the reagents and conditions required. Write a balanced equation and explain why it is possible to produce **two** different alcohols.

.....[5]

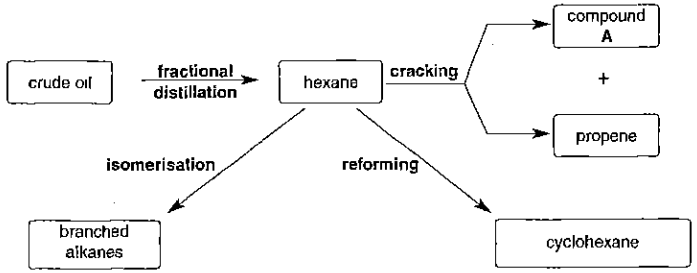
[Total : 16]

For Examiner's Use

Answer **all** questions.

1 The refined fractions of crude oil are used to make many organic compounds. In turn, these compounds are used to manufacture a great variety of products.

The reaction sequence below shows the production of hexane from fractional distillation of crude oil followed by cracking, reforming and isomerisation.



(a) The cracking of hexane produces propene and compound **A**.

(i) Complete a balanced equation for this cracking of hexane.

$C_6H_{14} \longrightarrow$ ..... + ... [1]

(ii) Name compound **A**. .....[1]

(b) The reforming of hexane produces cyclohexane.

Write a balanced equation for this reforming.

.....[1]

(c) The isomerisation of hexane produces **four** branched alkanes.

In the boxes below show the structural formulae and names of **two** of these branched isomers.

name	name .....

[4]

For Examiner's Use

(d) State why hydrocarbons such as hexane are both reformed and isomerised by oil companies.

.....

.....[1]

(e) Crude oil and its fractions are described as non-renewable fossil fuels. To reduce the demand for fossil fuels ethanol can be mixed with petrol. Ethanol is an example of a renewable biofuel.

(i) Explain what is meant by a *biofuel*.

.....

.....[1]

(ii) Why are fossil fuels *non-renewable* whereas ethanol is *renewable*?

.....

.....

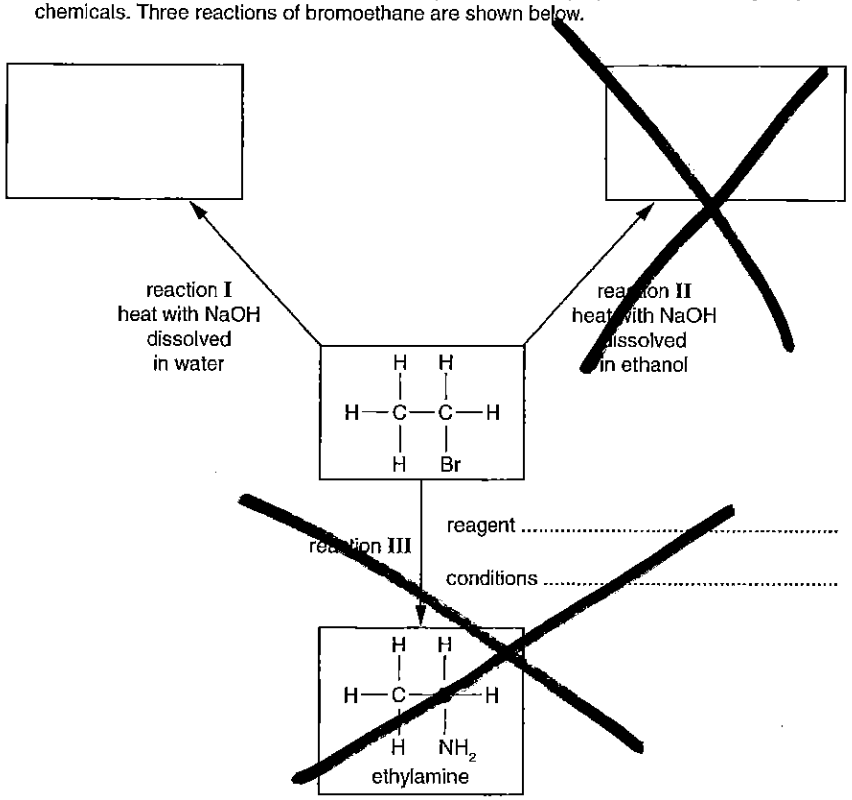
.....[2]

[Total : 11]

[Turn over

For Examiner's Use

2 Halogenoalkanes are useful synthetic reagents for the preparation of many important chemicals. Three reactions of bromoethane are shown below.



(a) **(i)** Identify the organic products in reactions **I** and **II** by writing their structural formulae in the relevant boxes. [2]

(ii) Name the **type** of reaction involved in

reaction **I**, ...

reaction **II**. .....[3]

(b) Write, in the space provided in the reaction scheme above, the reagent and conditions required to convert bromoethane into ethylamine in reaction **III**. [2]

For Examiner's Use

(c) **(i)** 2-bromobutane can react with ethanolic NaOH to form **two** structural isomers, each with a molecular formula of C_4H_8.

Draw and name each of the isomers.

isomer		
name	.....	.....

[4]

(ii) One of the isomers in **(c)** **(i)** can have *cis* and *trans* forms. In the boxes below, draw these *cis* and *trans* isomers.

cis isomer	*trans* isomer

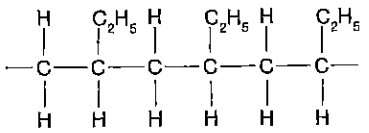
[2]

(iii) State **two** key structural features required for *cis-trans* isomerism to exist.

1. .....

2. .....[2]

(d) Each of the isomers drawn in **(c)**(i) can form a long-chain polymer. The structure below shows a section of one of these polymers.



(i) Draw a circle around the repeat unit. [1]

(ii) State the type of polymerisation. .....[1]

(iii) Identify which of the isomers in **(c)**(i) formed the polymer.

.....[1]

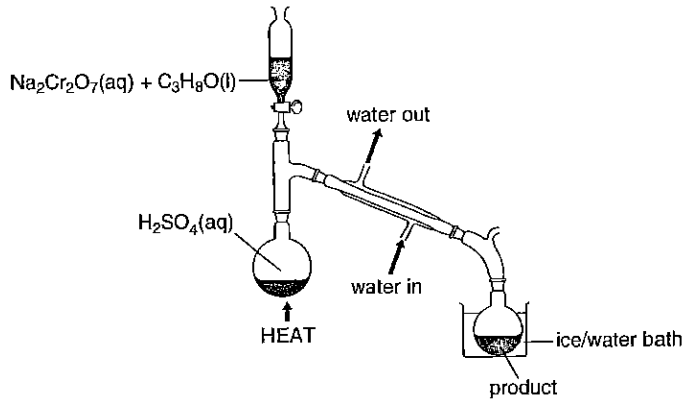
[Total : 18]

[Turn over

For Examiner's Use

3 A student was given the following instructions for the oxidation of an alcohol, C_3H_8O.

To 20 cm^3 of water in a flask, carefully add 6 cm^3 of concentrated sulphuric acid, and set up the apparatus as shown below.



Make up a solution containing 39.3 g of sodium dichromate(VI), $Na_2Cr_2O_7$, in 15 cm^3 of water, add 18.0 g of the alcohol, C_3H_8O, and pour this mixture into the dropping funnel.

Boil the acid in the flask. Add the mixture from the dropping funnel at such a rate that the product is slowly collected.

Re-distil the product and collect the fraction that boils between 48 °C and 50 °C.

(a) Identify the possible isomers of the alcohol C_3H_8O.

[2]

(b) The balanced equation for the reaction is:

$$3C_3H_8O + Na_2Cr_2O_7 + 4H_2SO_4 \longrightarrow 3C_3H_6O + Na_2SO_4 + Cr_2(SO_4)_3 + 7H_2O$$

(i) The mass of $Na_2Cr_2O_7$ used was 39.3 g. Calculate how many moles of $Na_2Cr_2O_7$ were used. (The molar mass of $Na_2Cr_2O_7$ is 262 g mol^{-1})

Answer .....[1]

For Examiner's Use

(ii) The amount of C_3H_8O used was 0.300 mol. Explain whether C_3H_8O or $Na_2Cr_2O_7$ was in excess.

.....

.....[1]

(iii) State the colour change that the student would observe during the reaction.

from ..... to ..... [2]

(c) The student obtained 5.22 g of the carbonyl compound, C_3H_6O.

(i) Calculate how many moles of C_3H_6O were produced in the experiment.

[2]

(ii) The theoretical yield of C_3H_6O is 0.300 mol. Calculate the percentage yield of C_3H_6O obtained by the student.

Answer .....[1]

(d) An **impure** sample of C_3H_6O obtained by a student was analysed using infra-red spectroscopy. The infra-red spectrum contained an absorption between 1680 and 1750 cm^{-1}. It also contained a broad absorption in the region 2550 to 3300 cm^{-1} due to the impurity.

Refer to the Data Sheet provided.

(i) What does the absorption at between 1680 and 1750 cm^{-1} indicate?

.....[1]

(ii) What does the broad absorption in the region 2550 to 3300 cm^{-1} indicate?

.....[1]

(iii) Identify which of the alcohols in **(a)** was used by this student. Explain your answer.

The alcohol used was .....

because .....

.....[1]

[Total : 12]

[Turn over

For Examiner's Use

4 An organic compound **A** was analysed and found to have a relative molecular mass of 62 and a composition by mass: C, 38.7%; H, 9.7%; O, 51.6%.

(a) (i) Calculate the empirical formula of compound **A**.

[2]

(ii) Deduce the molecular formula of compound **A**.

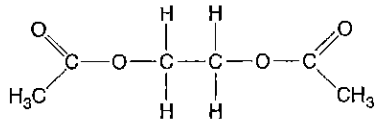
[1]

(b) The infra-red spectrum of compound **A** showed an absorption between 3230–3550 cm^{-1}.

State the functional group indicated by this absorption.

.....[1]

(c) One molecule of compound **A** can react with an excess of ethanoic acid, CH_3COOH, to produce the compound shown below.



Deduce the identity of compound **A**.

[1]

(d) Suggest why compound **A** has an unusually high boiling point of 198 °C.

.....

.....[1]

[Total : 6]

For Examiner's Use

5 Chlorine reacts readily with ethene in the dark but does not react with methane unless sunlight or another source of ultra violet light is present.

State and describe, with the aid of suitable equations,

- the mechanism of the reaction between chlorine and methane,
- the mechanism of the reaction between chlorine and ethene,
- the type of fission that the C*l*–C*l* bond undergoes in each of the mechanisms.

In this question, 1 mark is available for the quality of written communication.

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

[12]

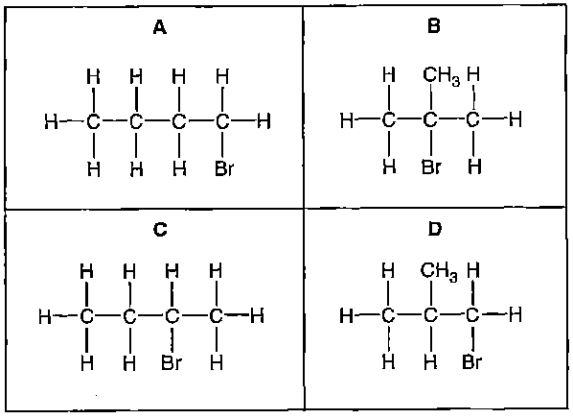
QWC [1]

[Total : 13]

For Examiner's Use

Answer **all** the questions.

1 This question is about halogenoalkanes **A** to **D**, shown below.



(a) Answer the questions that follow by using the appropriate letter **A**, **B**, **C** or **D**. Each letter may be used once, more than once or not at all.

(i) Which is 2-bromo-2-methylpropane?

..... [1]

(ii) Which could react with hot aqueous sodium hydroxide to produce butan-2-ol?

..... [1]

(iii) Which could react with hot aqueous sodium hydroxide to produce a tertiary alcohol?

..... [1]

(iv) Which **two** could react with hot ethanolic sodium hydroxide to produce but-1-ene?

..... and ..... [1]

For Examiner's Use

(b) Compound **A** can react with ammonia to produce an amine.

(i) Complete the equation for this reaction.

$CH_3CH_2CH_2CH_2Br + NH_3 \longrightarrow$ ..... + ... [1]

(ii) Name the organic product.

..... [1]

(iii) State a suitable solvent for this reaction.

..... [1]

(c) Compound **D** can react with aqueous hydroxide ions OH^-. The hydroxide ion is a nucleophile.

(i) Define the term *nucleophile*.

.....

..... [1]

(ii) Draw a *'dot-and-cross'* diagram of the OH^- ion. Show outer shell electrons only.

[2]

(iii) Identify the organic product formed when compound **D** reacts with aqueous OH^- ions.

[1]

[Total: 12]

For Examiner's Use

2 (a) (i) The brominated alkene, $C_3H_4Br_2$, has five possible structural isomers.

What is meant by the term *structural isomer*?

.....

..... [2]

(ii) Two of the structural isomers of $C_3H_4Br_2$ are drawn below.

Draw the other three **structural** isomers.

$CH_3CH{=}CBr_2$	$CH_3CBr{=}CHBr$	
1	**2**	**3**
	4	**5**

[3]

(iii) Name isomer **1**

..... [1]

(b) Isomer **2** in **(a)(ii)** shows *cis-trans* isomerism.

(i) Draw the *cis* and *trans* isomers of isomer **2**.

cis	*trans*

[2]

For Examiner's Use

(ii) State the approximate bond angle around each carbon atom involved in the C=C double bond of these *cis-trans* isomers.

..... [1]

(iii) Isomer **1** does **not** show *cis-trans* isomerism. Explain why not.

.....

..... [1]

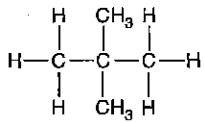
(iv) Identify **one** of your isomers, **3**, **4** or **5**, in **(a)(ii)** that **does** show *cis-trans* isomerism.

Isomer ..... **does** show *cis-trans* isomerism. [1]

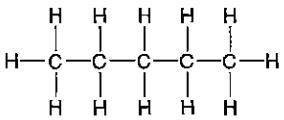
[Total: 11]

For Examiner's Use

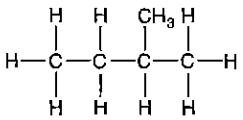
3 Each of the compounds, **G**, **H** and **I**, has the molecular formula C_5H_{12}.



G



H



I

(a) **(i)** Which compound has the highest boiling point?

..... [1]

(ii) Which compound is most likely to be a gas at room temperature?

..... [1]

(iii) State the type of intermolecular forces present in all three compounds.

..... [1]

(b) **G**, **H** and **I** all react with bromine as shown below.

$$C_5H_{12} + Br_2 \longrightarrow C_5H_{11}Br + HBr$$

The reaction is initiated by the formation of bromine free-radicals.

(i) What is meant by the term *free-radical*?

..... [1]

(ii) Write an equation to show the formation of bromine free-radicals.

..... [1]

(iii) State the type of bond breaking involved in the formation of bromine free-radicals.

..... [1]

(iv) Write equations to show the **two** propagation steps that lead to the formation of $C_5H_{11}Br$.

.....

..... [2]

For Examiner's Use

(c) Each of the compounds, **G**, **H** and **I** can react with bromine to form a mono-bromo compound, $C_5H_{11}Br$.

Deduce the number of possible structural isomers, each with formula $C_5H_{11}Br$, that could be made by the reaction of bromine with

(i) compound **G** .....

(ii) compound **H** .....

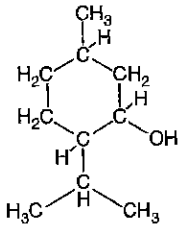
(iii) compound **I**. .....

[3]

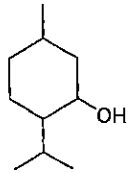
[Total: 11]

4 Menthol is a naturally occurring cyclic compound found in peppermint oil. It has been used in throat sprays and cough drops for many years.

The structural and skeletal formulae of menthol are shown below.



structural formula of menthol



skeletal formula of menthol

(a) (i) What is the molecular formula of menthol?

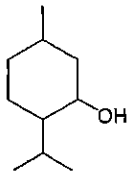
..... [1]

(ii) Identify the functional group present in menthol and classify it as either primary, secondary or tertiary.

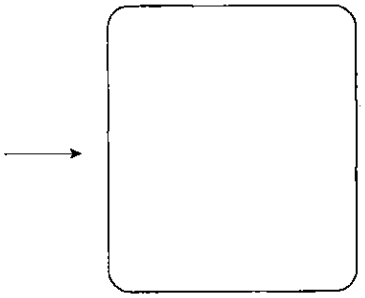
Functional group ..... Classification ..... [2]

(b) When menthol is reacted with hot concentrated sulphuric acid, H_2SO_4, two isomeric alkenes, each with formula $C_{10}H_{18}$, can be formed.

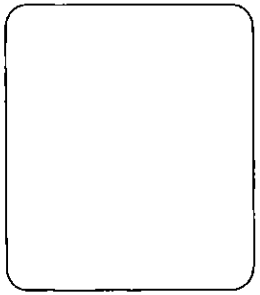
Draw the skeletal formula of each of the isomers formed.



menthol

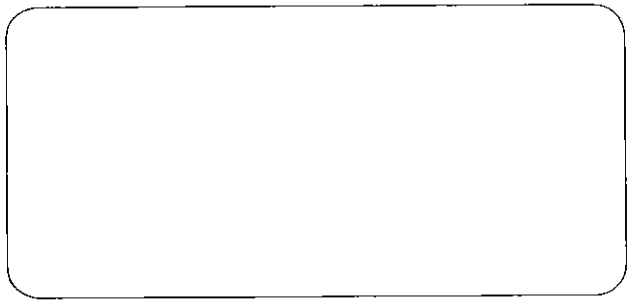


and



[2]

(c) Identify the organic product formed when menthol is reacted with ethanoic acid, CH_3COOH, in the presence of an acid catalyst. Draw its structure below.



[2]

[Total: 7]

For Examiner's Use

5 Ethene can be used to manufacture chloroethene $H_2C{=}CHCl$. This involves the following reactions.

step 1 $H_2C{=}CH_2 + Cl_2 \longrightarrow ClH_2C{-}CH_2Cl$

step 2 $ClH_2C{-}CH_2Cl \xrightarrow{500\ °C} H_2C{=}CHCl + HCl$

(a) (i) State the type of mechanism involved in **step 1**.

..... [2]

(ii) Complete, with the aid of curly arrows, the mechanism involved in step 1. Show any relevant dipoles and charges.

$H_2C{=}CH_2 \longrightarrow$ $\longrightarrow ClH_2C{-}CH_2Cl$

Cl
|
Cl

[4]

(b) The chloroethene (also known as vinyl chloride) produced can be polymerised to form poly(chloroethene) or PVC.

(i) Draw a section of the polymer, PVC, to show **two** repeat units.

[1]

For Examiner's Use

(ii) Describe the difficulties in the disposal of polymers in general and identify a specific additional problem with the disposal of PVC.

.....

.....

.....

.....

..... [3]

(iii) Outline the role of chemists in minimising damage to the environment during the disposal process.

.....

.....

..... [1]

[Total: 11]

For Examiner's Use

6 In this question, one mark is available for the quality of written communication.

Describe how oil companies use cracking, isomerisation and reforming to process fractions from crude oil.

For each of the three processes include relevant balanced equations and clearly state the importance of the products.

.... [7]

Quality of Written Communication [1]

[Total: 8]

For Examiner's Use

Answer **all** the questions.

1 Compound **A** is an alcohol with the following percentage composition by mass:

C, 60.0%; H, 13.3%; O, 26.7%.

(a) **(i)** Calculate the empirical formula of compound **A**.

[2]

(ii) The relative molecular mass of compound **A** is 60. Show that this agrees with the molecular formula C_3H_8O.

[1]

(b) Compound **A** is one of two possible isomers that are both alcohols. Draw the structure of each isomer.

[2]

(c) Compound **A** was refluxed with an excess of an oxidising agent to form compound **B**.

(i) State a suitable oxidising agent for this reaction.

.... [1]

(ii) State the colour change you would see during this oxidation.

From .... to .... [2]

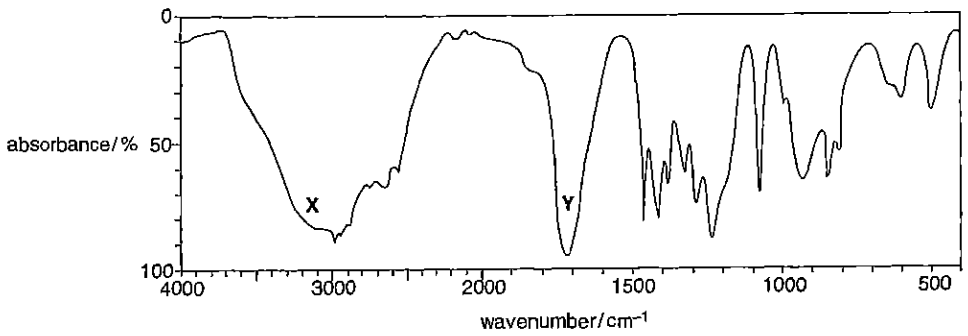
(iii) Explain what is meant by the term *reflux*.

....

.... [1]

For Examiner's Use

(d) The infra red spectrum of compound **B** is shown below.



Identify

(i) the absorption responsible for peak **X**

..... [1]

(ii) the absorption responsible for peak **Y**

..... [1]

(iii) the functional group present in compound **B**.

..... [1]

(e) Using your answer to **(d)**, explain which of the isomers in **(b)** is compound **A**.

.....

..... [1]

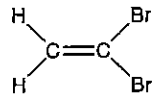
(f) Write a balanced equation for the oxidation of compound **A** to form compound **B**. Use [O] to represent the oxidising agent.

..... [2]

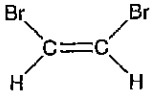
[Total: 15]

For Examiner's Use

2 Dibromoethene, $C_2H_2Br_2$, has two structural isomers **C** and **D**, shown below.



C



D

(a) **(i)** Name compound **C**.

..... [1]

(ii) What is the empirical formula of compound **D**?

..... [1]

(b) The reaction between either **C** or **D** and Br_2 can be used to show the presence of the C=C double bond.

(i) State what you would see when isomer **C** reacts with Br_2.

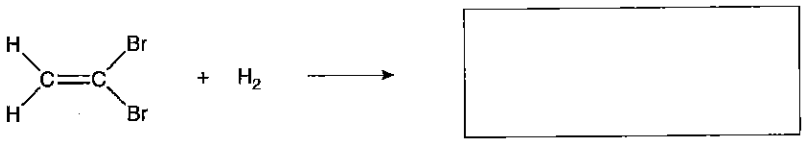
..... [1]

(ii) State the type of mechanism for the reaction between isomer **C** and Br_2.

..... [2]

(c) Isomers **C** and **D** can both behave as alkenes. For each of the following reactions, state the conditions, if any, and identify the organic products that can be formed.

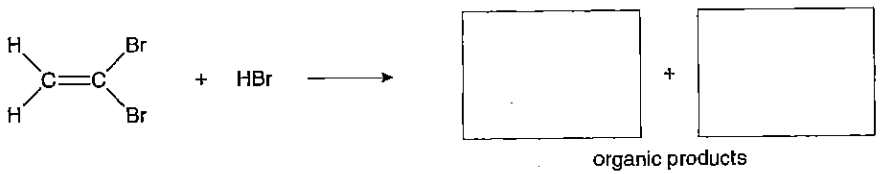
(i) Isomer **C** reacts with H_2.



conditions ..... [2]

For Examiner's Use

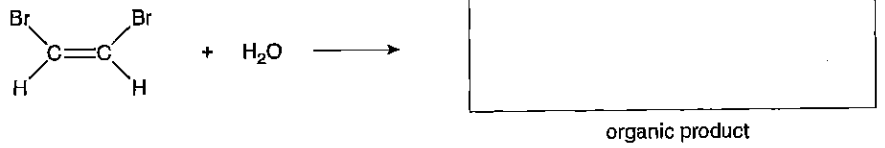
(ii) Isomer **C** reacts with HBr.



organic products

[2]

(iii) Isomer **D** reacts with H_2O.



organic product

conditions .....

..... [3]

[Total: 12]

For Examiner's Use

3 In this question, one mark is available for the quality of written communication.

(a) Explain why methane does not react with reagents such as nucleophiles or electrophiles.

.....

.....

.....

..... [2]

(b) Name and describe the mechanism for the reaction between methane and bromine.

State the type of bond fission involved in the mechanism and explain why it is difficult to produce a single organic product.

In your answer, include any relevant equations and conditions.

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..... [9]

Quality of Written Communication [1]

[Total: 12]

For Examiner Use

4 Halogenoalkanes undergo hydrolysis with hot aqueous NaOH to form alcohols.

(a) **(i)** Write a balanced equation for the hydrolysis of 1-bromobutane, C_4H_9Br.

..... [1]

(ii) Describe, with the aid of curly arrows and relevant dipoles, the mechanism for the hydrolysis of 1-bromobutane with hydroxide ions, OH^-.

[3]

(b) The rates of hydrolysis of 1-chlorobutane, 1-bromobutane, and 1-iodobutane were compared by an experiment using $AgNO_3$ solution. Aqueous $AgNO_3$ was added to each halogenoalkane. The rates of hydrolysis were measured by timing the appearance of the silver halide precipitate.

(i) Place the three halogenoalkanes in the order of their rates of hydrolysis with the compound with the fastest rate first.

fastest .....

.....

slowest ..... [1]

(ii) Explain the order in (i).

.....

.....

..... [1]

[Total: 6]

For Examiner' Use

5 The question below concerns some of the chemistry involved in the brewing of beer.

Yeast ferments glucose, $C_6H_{12}O_6$, anaerobically (without oxygen) to produce ethanol and carbon dioxide.

(a) Balance the following equation for the anaerobic fermentation of glucose.

$$C_6H_{12}O_6 \longrightarrow \ldots\ldots C_2H_5OH + \ldots\ldots CO_2$$

[1]

(b) A batch containing 36.0 kg of glucose, $C_6H_{12}O_6$, produced 2.30 kg of ethanol, C_2H_5OH.

(i) Calculate the number of moles of glucose used.

[2]

(ii) Use the equation in **(a)** to deduce the maximum number of moles of ethanol that can be produced from 36.0 kg of glucose.

M_r $C_2H_5OH = 46$

[1]

(iii) Calculate the actual number of moles of ethanol produced by this batch fermentation.

[1]

(iv) Calculate the percentage yield of ethanol.

[1]

(c) The ethanol present in an alcoholic drink passes into the bloodstream and the liver is involved in breaking down the ethanol. The first stage of this breakdown involves the following reaction.

$$CH_3CH_2OH + [O] \longrightarrow CH_3CHO + H_2O. \qquad \textbf{reaction 5.1}$$

CH_3CHO is then oxidised to other products.

(i) Name the functional group present in CH_3CHO.

..... [1]

(ii) Suggest **one** possible oxidation product that can be formed from CH_3CHO.

..... [1]

(d) Methylated spirit contains ethanol and methanol, CH_3OH. Methylated spirit is unfit for drinking because an oxidation product of methanol causes liver damage and blindness. The methanol is oxidised in the body in a similar oxidation to that of ethanol shown in **reaction 5.1**.

Write an equation for the oxidation of methanol.

..... [2]

(e) Methanol can be added to petrol.

(i) Write a balanced equation for the complete combustion of methanol.

..... [1]

(ii) Suggest why methanol is added to petrol.

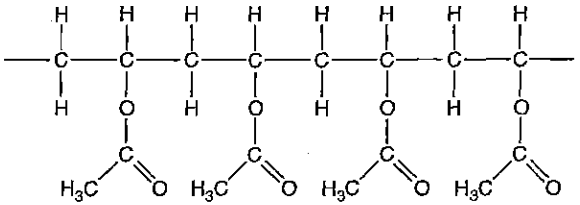
..... [1]

(f) Methanol, CH_3OH, can be reacted with carbon monoxide to produce ethanoic acid, CH_3COOH.

Construct an equation for this reaction.

..... [1]

(g) Much of the ethanoic acid produced is used in the manufacture of the monomer ethenyl ethanoate (vinyl acetate). The monomer is then used to produce the polymer, polyvinyl acetate (PVA), part of which is shown below.



(i) Draw a circle around the repeat unit in PVA. [1]

(ii) Draw the structure of the monomer ethenyl ethanoate (vinyl acetate).

[1]

[Total: 15]

For Examiner Use

Answer **all** the questions.

1 **(a)** The alkanes in crude oil can be separated because they have different boiling points.

The table below shows the boiling points of some alkanes.

alkane	boiling point/°C	M_r
butane	0	58
pentane	36	72
hexane	69	86
2-methylbutane	28	72
dimethylpropane	10	72
3-methylpentane		86
2,3-dimethylbutane	58	86

(i) Explain the trend in boiling points of the straight chain alkanes.

.....

.....

.....[2]

(ii) Explain the difference in the boiling points of the three isomers with $M_r = 72$.

.....

.....

.....[2]

(iii) Use the data in the table to predict the boiling point of 3-methylpentane.

.....[1]

(b) In industry, alkanes are processed by isomerisation and by reforming.

(i) Use skeletal formulae to write an equation for the isomerisation of pentane into dimethylpropane.

[2]

(ii) Write an equation to show how pentane can be reformed.

[2]

(iii) State why straight chain alkanes are processed by isomerisation and reforming.

.....

.....[1]

[Total: 10]

2 Alkanes are unreactive and do not react with either nucleophiles or electrophiles.

(a) Explain the lack of reactivity in an alkane such as propane.

.....

.....

.....

.....[2]

(b) Under certain conditions propane reacts with halogens to form halogenoalkanes.
An example is shown below.

$$CH_3CH_2CH_3 + Cl_2 \longrightarrow CH_3CH_2CH_2Cl + HCl$$

The reaction is described as a free-radical substitution reaction. It is initiated by the fission of the bond in Cl_2.

(i) What is meant by the term *free-radical*?

.....[1]

(ii) State the type of fission that takes place when the bond in Cl_2 breaks.

.....[1]

(iii) State the conditions necessary for the fission of the bond in Cl_2.

.....[1]

(iv) The reaction mechanism for the reaction above involves two propagation steps.

Write equations to show the two propagation steps.

step 1 .....[1]

step 2 .....[1]

(v) Free-radical reactions are difficult to control and often result in a complex mixture of organic products. In the reaction of propane with chlorine some hexane is also formed.

Suggest how hexane could have been formed.

.....[1]

(c) Propane can be used as a fuel in cookers whilst camping.

(i) Write a balanced equation for the complete combustion of propane.

.....[1]

(ii) Explain why propane cookers should only be used in a well-ventilated space.

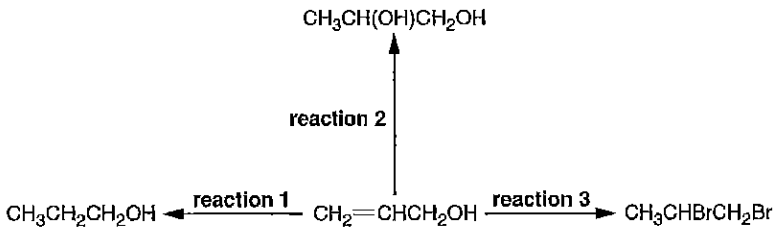
.....

.....[1]

[Total: 10]

3 Prop-2-en-1-ol, $CH_2{=}CHCH_2OH$, is a colourless liquid with a pungent smell. It is produced in industry to make resins, plasticisers and many other chemicals.

(a) The reaction scheme below shows how prop-2-en-1-ol can be used for the production of a variety of chemicals.



State the reagent(s) and catalyst, if any, for each of **reactions 1**, **2** and **3**.

(i) **reaction 1** reagent(s) .....

catalyst ..... [2]

(ii) **reaction 2** reagent(s) .....

catalyst ..... [2]

(iii) **reaction 3** reagent(s) ..... [1]

(b) $CH_2{=}CHCH_2OH$ also reacts with bromine to form $CH_2BrCHBrCH_2OH$.

Describe, with the aid of curly arrows, the mechanism involved. Show any relevant dipoles.

[4]

(c) Prop-2-en-1-ol polymerises rapidly.

(i) Show three repeat units and draw a circle around one repeat unit.

[2]

(ii) Write a balanced equation for this polymerisation.

[2]

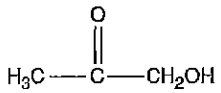
(iii) Name the polymer. .....[1]

(d) The products from **reactions 1** and **2** are $CH_3CH_2CH_2OH$ and $CH_3CH(OH)CH_2OH$, respectively. Both undergo oxidation reactions with acidified dichromate ions, $H^+/Cr_2O_7^{2-}$.

(i) Write a balanced equation for the reaction of $CH_3CH_2CH_2OH$ with excess $H^+/Cr_2O_7^{2-}$ under reflux.
Use [O] to represent the oxidising mixture.

.....[2]

(ii) When $CH_3CH(OH)CH_2OH$ is oxidised with $H^+/Cr_2O_7^{2-}$ it produces a mixture of organic products, one of which is shown below.



hydroxypropanone

Suggest the structures of **two** other possible oxidation products from this reaction.

[2]

[Total: 18]

4 A chemistry student was interested in aromatherapy and decided to investigate rose oil which can be extracted from both the flowers and the leaves of roses.

(a) The student separated an organic liquid, compound **A**, from rose oil. Compound **A** has a relative molecular mass of 154 and contains 77.9% C, 11.7% H and 10.4% O by mass.

Calculate the molecular formula of compound **A**.

molecular formula = ...[3]

(b) The student reacted compound **A** with bromine and observed that the bromine was decolourised.

(i) What conclusion can be drawn from this observation?

.....[1]

(ii) Further investigation revealed that 0.0100 mol of compound **A** reacted exactly with 3.196 g of bromine.

Calculate the number of moles of bromine, Br_2, that reacted.

answer = ... mol [2]

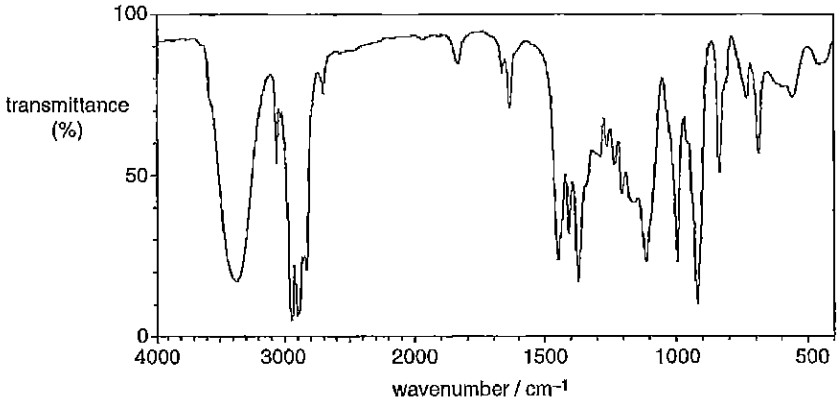
(iii) What conclusion could the student draw about compound **A** from this investigation?

.....

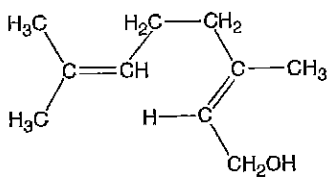
.....[1]

(c) The student analysed the infra-red spectrum of compound **A** and concluded that the compound is an alcohol.

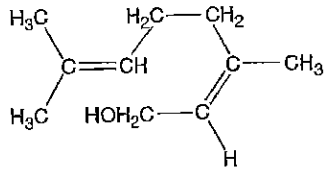
On the infra-red spectrum below label, with a letter **X**, the absorption that confirms that compound **A** is an alcohol. [1]



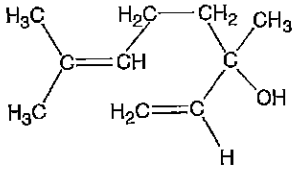
(d) After careful research the student concluded that **A** was one of the three compounds below.



geraniol



nerol



linalool

The student heated compound **A** with acidified potassium dichromate and the orange colour did **not** turn green. The student was therefore able to identify compound **A** as one of the three compounds shown above.

(i) Compound **A** is .....[1]

(ii) Explain your reasoning.

.....

.....[1]

(e) Suggest a reagent that would react with the alcohol group in compound **A** to produce a gas.

State the reagent and identify the gas and the organic product.

reagent .....

gas .....

organic product

[3]

[Total: 13]

5 In this question, one mark is available for the quality of spelling, punctuation and grammar.

The rates of hydrolysis of 1-chloropentane, 1-bromopentane and 1-iodopentane are different.

- Briefly outline how you would compare the reaction rates.
- Explain why 1-chloropentane, 1-bromopentane and 1-iodopentane react at different rates and state the order of reactivity.
- Use suitable equations in your answer.

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.....[8]

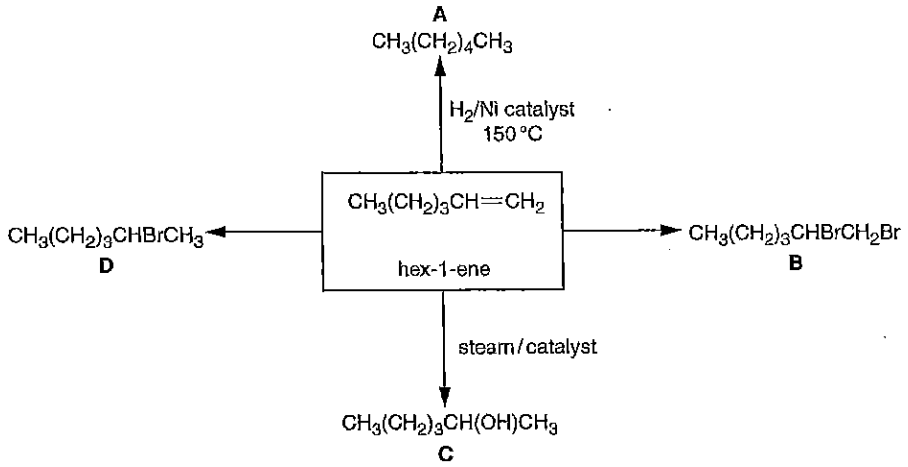
Quality of Written Communication [1]

[Total: 9]

END OF QUESTION PAPER

Answer **all** the questions.

1 Hex-1-ene, $CH_3(CH_2)_3CH{=}CH_2$, reacts as shown below.



(a) (i) What is the molecular formula of compound **A**? ..... [1]

(ii) What is the empirical formula of compound **B**? ..... [1]

(iii) Name compound **C**. ..... [1]

(iv) State a suitable reagent(s) for converting hex-1-ene into compound **D**.

..... [1]

(b) (i) Describe, with the aid of curly arrows, the mechanism for the formation of compound **B** from hex-1-ene.
Show any relevant dipoles and lone pairs of electrons.

hex-1-ene → **intermediate** → compound **B**

[4]

(ii) Name this type of reaction.

.....[1]

(iii) State what you would see during this reaction.

.....[1]

(c) Hex-1-ene, $CH_3(CH_2)_3CH{=}CH_2$, can form a polymer.

(i) Write a balanced equation for the polymerisation of hex-1-ene.

[2]

(ii) Name the polymer. .....[1]

[Total: 13]

2 There are **four** structural isomers of $C_4H_{10}O$ that are alcohols.

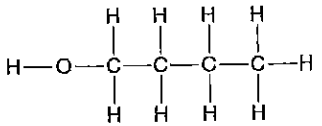
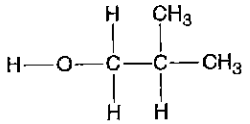
(a) What is meant by *structural isomers*?

.....

.....[1]

(b) Alcohols can be classified as either primary, secondary or tertiary.

Draw, name and classify each of the **four** structural isomers of $C_4H_{10}O$ by completing the boxes in the table below. Some have been completed for you.

alcohol	name	classification
	butan-1-ol	primary
	butan-2-ol	
		
		tertiary

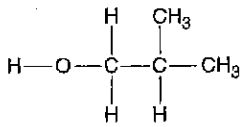
[6]

(c) Alcohols such as butan-1-ol have high boiling points due to the presence of hydrogen bonds.

Draw two molecules of butan-1-ol linked by a hydrogen bond. Include any relevant dipoles and lone pairs of electrons.

[3]

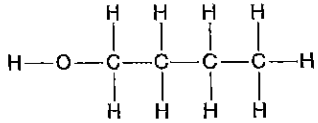
(d) An ester is formed when ethanoic acid, CH_3COOH, reacts with the alcohol shown below.



Draw the ester formed.

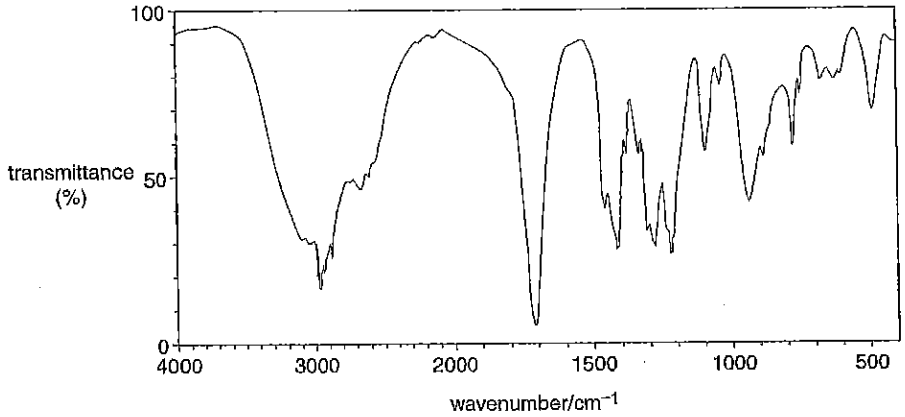
[1]

(e)



butan-1-ol

Butan-1-ol was oxidised using acidified potassium dichromate. The organic product was analysed by infra-red spectroscopy. The infra-red spectrum obtained is shown below.



(i) Use the spectrum to identify the organic product. Explain your reasoning.

.....

.....

.....

.....

..... [3]

(ii) Write a balanced equation for this oxidation. Use [O] to represent the oxidising agent.

..... [2]

[Total: 16]

3 Compound **X** is a hydrocarbon containing 85.7% C by mass.

(a) (i) Calculate the empirical formula of compound **X**.

empirical formula = ...[2]

(ii) The relative molecular mass of compound **X** is 56. Show that the molecular formula of compound **X** is C_4H_8.

[1]

(b) Compound **X** is a *cis* isomer.

Draw the **skeletal** formulae of compound **X** and its *trans* isomer.

compound **X**	*trans* isomer

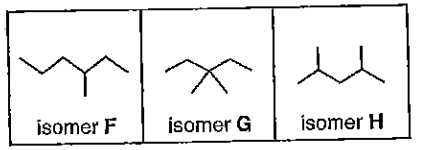
[2]

[Total: 5]

4 Petrol is a blend or mixture of many different hydrocarbons.

Oil companies use a variety of techniques such as isomerisation and reforming to produce the hydrocarbons which can be mixed together to give the correct blend.

(a) Isomerisation of heptane, C_7H_{16}, produces a mixture of branched structural isomers, three of which are shown in the boxes below.



(i) Draw, using skeletal formulae, **two** other branched structural isomers of heptane.

[2]

(ii) Name isomer **G**. .....[1]

(iii) Isomers **F**, **G** and **H** have different boiling points.
Which of the three isomers has the highest boiling point?

.....[1]

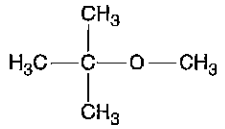
(b) Heptane can be reformed to produce methylcyclohexane as one of the products.

Write a balanced equation for the reforming of heptane into methylcyclohexane.

[2]

(c) Oxygen-containing compounds can be added to improve the efficiency and performance of fuels.

A commonly used oxygen-containing compound is MTBE, shown below.



MTBE

(i) Calculate the percentage, by mass, of oxygen in MTBE. Give your answer to three significant figures.

answer = ...[2]

(ii) Write a balanced equation for the complete combustion of MTBE.

[2]

(d) The compounds in petrol have high volatility.

(i) What is meant by *high volatility*?

.....

..... [1]

(ii) Suggest **one** disadvantage if the volatility of a petrol is too high.

.....

..... [1]

[Total: 12]

5 **(a)** In this question, one mark is available for the quality of use and organisation of scientific terms.

Halogenoalkanes can be converted into alcohols, [redacted]

Give an example of each of these conversions including reagents, conditions and balanced equations.

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.....[9]

Quality of Written Communication [1]

(b) Describe the mechanism for the preparation of an alcohol from a halogenoalkane. Use curly arrows to show the movement of electrons. Show any relevant dipoles and lone pairs of electrons.

[4]

[Total: 14]

END OF QUESTION PAPER

Answer **all** the questions.

1 Fuels are an important part of our everyday life. Crude oil is a source of hydrocarbons such as $C_{14}H_{30}$.

$C_{14}H_{30}$ is cracked into octane which can be used as a fuel. To improve its efficiency as a fuel, octane is processed into branched chain alkanes and cycloalkanes.

(a) What is meant by a *hydrocarbon*?

.....

..... **[1]**

(b) Write an equation for the cracking of $C_{14}H_{30}$ to form octane.

..... **[1]**

(c) Octane can be reformed into 1,2-dimethylcyclohexane, $CH_3C_6H_{10}CH_3$, and another product.

(i) Draw the structure of 1,2-dimethylcyclohexane.

[1]

(ii) Identify the other product formed.

..... **[1]**

(d) Isomerisation of octane can produce 2,2,3-trimethylpentane.

(i) Draw the structure of 2,2,3-trimethylpentane.

[1]

(ii) Write an equation for the complete combustion of 2,2,3-trimethylpentane.

..... **[2]**

(e) Scientists are looking for alternatives to fossil fuels and are developing 'bio-fuels' such as ethanol. Ethanol is a renewable fuel and it is thought to be more environmentally friendly than fossil fuels.

(i) Explain why ethanol is *renewable*.

.....

.....

..... **[2]**

(ii) Suggest why ethanol is thought to be *environmentally friendly*.

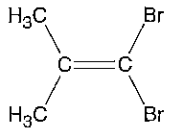
.....

.....

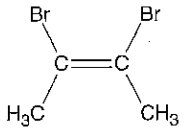
..... **[1]**

[Total: 10]

2 Compounds **A** and **B** are both dibromoalkenes with the molecular formula, $C_4H_6Br_2$. Compounds **A** and **B** are isomers.



A



B

(a) (i) Name compound **A**.

..... **[1]**

(ii) Calculate the percentage, by mass, of Br in compound **A**.

answer = ... % **[2]**

(iii) Draw another structural isomer of $C_4H_6Br_2$.

[1]

(b) The reaction between isomer **B** and Br_2 can be used to show the presence of the C=C double bond.

(i) State what you would see when isomer **B** reacts with Br_2.

..... **[1]**

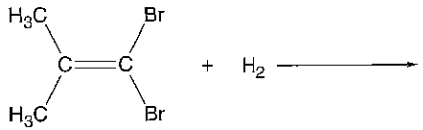
(ii) State the type of reaction mechanism for this reaction.

..... **[1]**

(iii) What is the molecular formula and the empirical formula of the organic product?

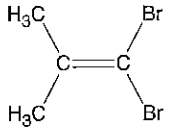
molecular formula = ... empirical formula = ... **[2]**

(c) For the reaction between isomer **A** and H_2, identify the organic product and state the conditions used.

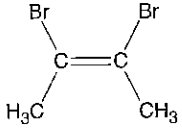


conditions..... **[2]**

(d) Isomers **A** and **B**, shown below, both react with HBr.



A



B

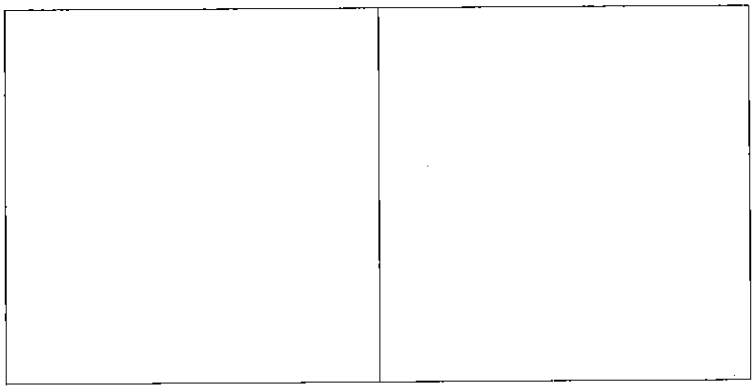
(i) Explain why **A** can produce two different structural isomers but **B** only one.

.....

.....

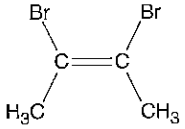
..... **[1]**

(ii) Identify the two structural isomers formed when **A** reacts with HBr.



[2]

(e) Isomer **B**, shown below, can be converted into 2,3-dibromobutan-2-ol.



B

(i) Draw the skeletal formula of 2,3-dibromobutan-2-ol.

[1]

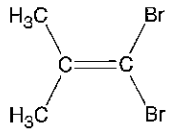
(ii) Suggest the reagent and conditions that could be used for the conversion.

reagent .....

conditions .....

..... **[2]**

(f) Isomer **A**, shown below, can form an addition polymer.



A

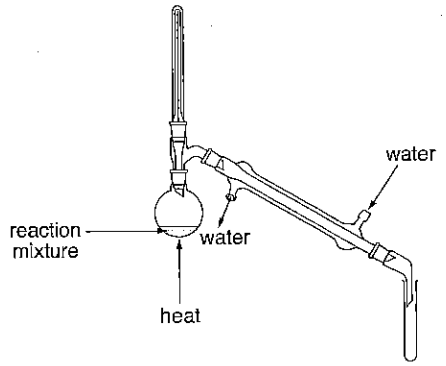
Draw a section of the polymer including two repeat units.

[2]

[Total: 18]

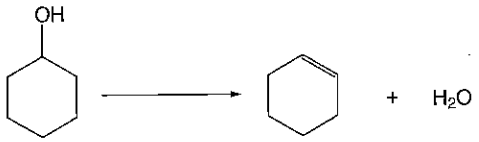
3 Cyclohexene, C_6H_{10}, can be prepared from cyclohexanol, $C_6H_{11}OH$, by the dehydration method described below.

A reaction mixture of 5.0 g cyclohexanol and 3.0 cm^3 of concentrated sulphuric acid, H_2SO_4, was placed in a round-bottomed flask and the apparatus arranged for distillation as shown below. An impure liquid, consisting of two immiscible layers, was collected after distillation.



The upper organic layer was separated and dried. Finally it was re-distilled to yield 1.8 g of cyclohexene.

The equation for the preparation is shown below.



(a) (i) What is the relative molecular mass of cyclohexanol?

..... **[1]**

(ii) How many moles of cyclohexanol were used in the experiment?

answer = ... mol **[1]**

(iii) Calculate the percentage yield of cyclohexene in the experiment.

Give your answer to **two** significant figures.

% yield = ... **[3]**

(b) It was thought that unreacted cyclohexanol was present.

(i) Explain how infra-red spectroscopy could be used to show that cyclohexanol was present. Refer to the *Data Sheet* in your answer.

.....

.....

..... **[2]**

(ii) A chemical test could have been used to show that an alcohol was present.

State the reagent and the expected observation.

reagent .....

observation ..... **[2]**

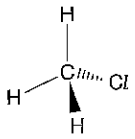
(iii) Draw the structure of the organic product that would have been formed in **(ii)** if cyclohexanol was the alcohol.

[1]

[Total: 10]

4 Halogenoalkanes are polar molecules that react with nucleophiles.

(a) The displayed formula of chloromethane is shown below. Label the dipole on the C–Cl bond and state the value of the H–C–Cl bond angle.

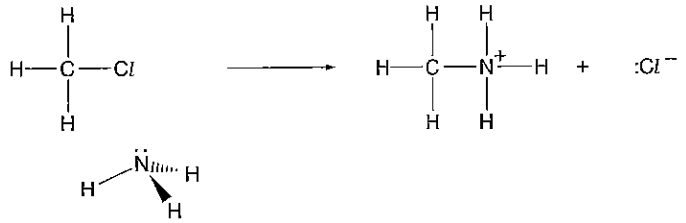


bond angle = ...° **[2]**

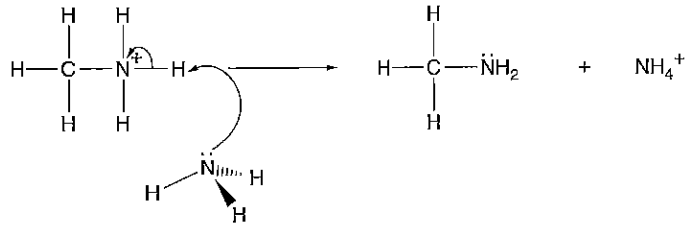
(b) Chloromethane reacts with ammonia in a nucleophilic substitution reaction.

Part of the mechanism for this reaction is shown below.

Step 1



Step 2



(i) What is meant by the term *nucleophile*?

..... **[1]**

(ii) Add 'curly arrows' to **step 1** of the mechanism to show the movement of electron pairs.

[2]

(iii) Deduce a balanced equation for the **overall** reaction.

..... **[1]**

(iv) Name the organic product. ..... **[1]**

(c) Ammonia was reacted with iodomethane rather than with chloromethane.

What would happen to the rate of reaction? Explain your answer.

.....

.....

..... **[2]**

[Total: 9]

TURN OVER FOR QUESTION 5

5 **(a)** Explain why alkanes, such as pentane, do not react with reagents such as nucleophiles and electrophiles.

.....

.....

.....

..... **[2]**

(b) In this question, one mark is available for the quality of use and organisation of scientific terms.

- Name and describe the mechanism for the reaction between pentane and bromine.
- State the type of bond fission involved in this mechanism.
- Explain why it is difficult to produce a single organic product.

In your answer, include any relevant equations and conditions.

.....

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..... **[10]**

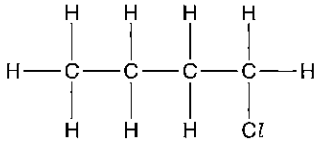
Quality of Written Communication **[1]**

[Total: 13]

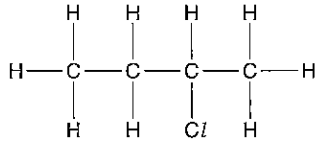
END OF QUESTION PAPER

Answer **all** the questions.

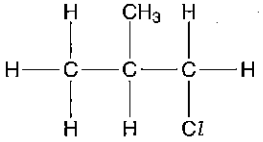
1 This question is about halogenoalkanes **A** to **D**, shown below.



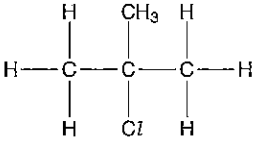
A



B



C



D

(a) Answer the questions that follow by using the appropriate letter **A, B, C** or **D.**

Each letter may be used once, more than once or not at all.

(i) Which is 2-chloro-2-methylpropane? ..... **[1]**

(ii) Which could react with hot aqueous sodium hydroxide to produce butan-2-ol? ..... **[1]**

(iii) Which could react with hot aqueous sodium hydroxide to produce a tertiary alcohol? ..... **[1]**

(iv) Which **two** could react with hot ethanolic sodium hydroxide to produce but-1-ene? ..... and ..... **[1]**

(b) Compound **C** can react with ammonia to produce an amine.

(i) Draw the organic product.

[1]

(ii) State a solvent for this reaction.

.....[1]

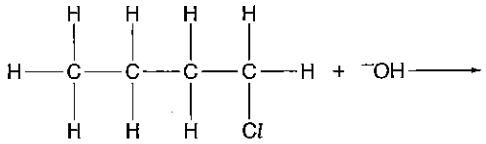
(c) Compound **A** can react with aqueous hydroxide ions, OH^-. The hydroxide ion is a nucleophile.

(i) Define the term *nucleophile.*

.....

.....[1]

(ii) Complete, with the aid of curly arrows, the mechanism involved in this reaction. Show any relevant dipoles and charges.



compound **A**

[3]

[Total: 10]

2 The chlorinated alkene, $C_3H_4Cl_2$, has five structural isomers that are alkenes and two other structural isomers that are not alkenes.

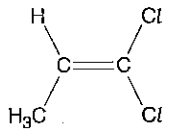
(a) (i) What is meant by the term *structural isomer*?

.....

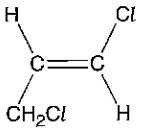
.....

.....[2]

(ii) Two of the structural isomers of $C_3H_4Cl_2$ are drawn below.



isomer **1**



isomer **2**

Draw the other three **structural** isomers, **3–5**, of $C_3H_4Cl_2$ that are alkenes.

isomer **3**	isomer **4**	isomer **5**

[3]

(iii) Name isomer **1** .....[1]

(iv) Draw one structural isomer of $C_3H_4Cl_2$ that is **not** an alkene.

[1]

(b) Another type of isomerism is *cis-trans* isomerism.

Why can some alkenes have *cis* and *trans* isomers?

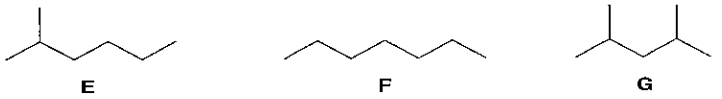
.....

.....

..... **[2]**

[Total: 9]

3 Each of the compounds, **E**, **F** and **G**, has the formula C_7H_{16}.



E **F** **G**

(a) **(i)** Which of **E**, **F** or **G** has the highest boiling point? ..... **[1]**

(ii) State the type of intermolecular forces present in all three compounds.

..... [1]

(iii) Identify another isomer of C_7H_{16} that is likely to have a boiling point lower than the boiling points of **E**, **F** or **G**.

[1]

(b) **E**, **F** and **G** all react with chlorine as shown below.

$$C_7H_{16} + Cl_2 \rightarrow C_7H_{15}Cl + HCl$$

The reaction is initiated by the formation of chlorine free-radicals.

(i) What is meant by the term *free-radical*?

..... **[1]**

(ii) Write an equation to show the formation of chlorine free-radicals.

..... **[1]**

(iii) State the type of bond breaking involved in the formation of chlorine free-radicals.

..... **[1]**

(iv) Write equations to show the **two** propagation steps that lead to the formation of $C_7H_{15}Cl$.

.....

..... **[2]**

(v) Explain, with the aid of an equation, how $C_{14}H_{30}$ could be formed in this reaction.

..... **[1]**

(c) Compounds **E** and **G** can react with chlorine to form a mono-chloro compound, $C_7H_{15}Cl$.

Deduce the number of possible structural isomers, each with formula $C_7H_{15}Cl$, that could be made by the reaction of chlorine with

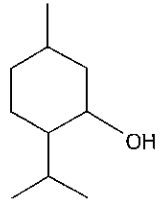
(i) compound **E**, ... **[1]**

(ii) compound **G**. ..... **[1]**

[Total: 11]

4 Menthol is a naturally occurring cyclic alcohol found in peppermint oil. It has been used in throat sprays and cough drops for many years.

The skeletal formula of menthol is shown below.



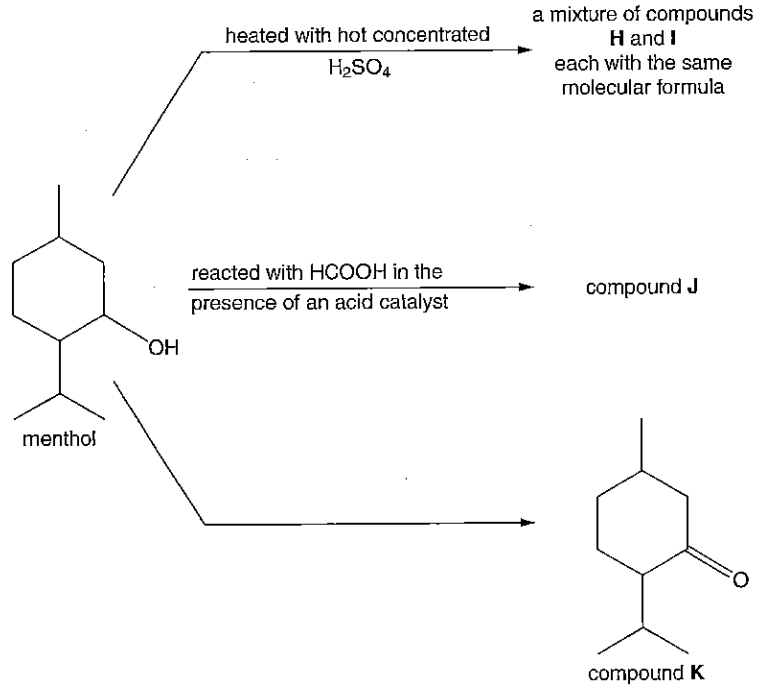
(a) **(i)** What is the molecular formula of menthol?

..... **[1]**

(ii) Classify menthol as a primary, secondary or tertiary alcohol.

..... **[1]**

(b) The reaction scheme below shows some of the reagents and conditions needed to convert menthol into four **organic** compounds **H**, **I**, **J** and **K**.



(i) Draw compounds **H** and **I**.

[2]

(ii) State the functional group in compound **J**.

..... [1]

(c) Menthol can be oxidised to form compound **K**.

(i) State the reagents and conditions.

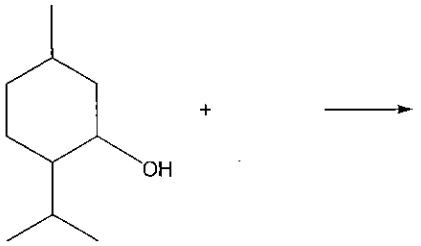
.....

..... [2]

(ii) State what you would see during the oxidation.

..... [1]

(iii) Write a balanced equation for the oxidation.
Use **[O]** to represent the oxidising agent.



[1]

(iv) Explain how you could use infra-red spectroscopy to confirm that no menthol remains.

.....

..... [1]

[Total: 10]

5 In this question, one mark is available for the quality of use and organisation of scientific terms.

(a) Crude oil is a complex mixture of hydrocarbons which is initially separated by fractional distillation. Some of the resultant fractions are then further refined by cracking, isomerisation or reforming.

- Explain why the crude oil can be separated into fractions by using fractional distillation. Outline, with the aid of equations, the three processes in the refining of the fractions. Explain why the three processes are necessary in the production of fuels.
- Explain why, in the long term, ethanol could supplement the use of oil-based fuels.
- Write an equation for the combustion of ethanol.

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..... [13]

Quality of Written Communication [1]

(b) Propene is a by-product of the refining of oil fractions.

Propene undergoes addition polymerisation to form poly(propene).

(i) Write an equation for the formation of poly(propene).

..... **[1]**

(ii) Draw a section of the polymer formed from propene. Show **two** repeat units.

[1]

(c) Propene can also be converted into alcohols.

State the reagents and conditions for this conversion and identify the organic products.

(i) reagents and conditions,

.....

..... **[2]**

(ii) organic products.

[2]

[Total: 20]

END OF QUESTION PAPER

For Examiner's Use

Answer **all** the questions.

1 Oxides of nitrogen such as NO and NO_2 are gases that pollute the atmosphere. They are produced during the combustion of petrol in car engines.

(a) Table 1.1 lists the enthalpy changes of formation of NO and NO_2.

Table 1.1

compound	$\Delta H^{\ominus}_f$/kJ mol^{-1}
NO	+90
NO_2	+33

(i) Define the term *standard enthalpy change of formation*.

.....

.....

.....**[2]**

(ii) Write an equation, including state symbols, to represent the standard enthalpy change of formation of NO_2(g).

.....**[2]**

(iii) Use the data in Table 1.1 to calculate the enthalpy change for the following reaction.

$$2NO(g) + O_2(g) \longrightarrow 2NO_2(g)$$

[3]

(b) Oxides of nitrogen only form under high energy conditions such as during lightning strikes or in internal combustion engines.

Suggest why this is so.

.....

.....**[1]**

(c) Modern cars have 'catalytic converters' in their exhausts to convert nitrogen oxides into less harmful substances. One reaction that occurs is as follows.

$$\_\_CO(g) + \_\_NO_2(g) \longrightarrow \_\_CO_2(g) + \_\_N_2(g)$$

(i) Balance this equation by writing the appropriate numbers in the spaces. [1]

(ii) What **type** of catalysis occurs in the catalytic converter? Explain your answer.

.....

.....

.....

.....[2]

(iii) Explain how this type of catalyst provides a different pathway for the reaction with a lower activation energy.

.....

.....

.....

.....[2]

(iv) Suggest why a catalytic converter is designed to have a large surface area?

.....

.....

.....

.....[2]

[Total : 15]

2 *Arcton 133* is a CFC with the molecular formula $C_2H_2ClF_3$.

(a) When *Arcton 133* is released into the atmosphere, its molecules can absorb energy. The C-Cl bond breaks forming free radicals.

$$C_2H_2ClF_3 \longrightarrow C_2H_2F_3^{\bullet} + Cl^{\bullet}$$

(i) What source of energy is required for this reaction to take place?

.....[1]

(ii) Chlorine free radicals catalyse the breakdown of ozone, O_3.

Write **two** equations to show how this happens.

.....

.....[2]

(iii) Write an equation for the overall reaction in **(a) (ii)**.

.....[1]

(iv) What **type** of catalysis is shown here? Explain your answer.

.....

.....

.....[2]

(b) In some applications, CFCs are being replaced by hydrocarbons such as alkanes.

(i) What is the M_r of *Arcton 133*, $C_2H_2ClF_3$?

[1]

(ii) The formulae of some alkanes are shown below.

C_5H_{12} C_6H_{14} C_7H_{16} C_8H_{18} C_9H_{20}

Draw a circle around the molecular formula of the alkane whose M_r is most similar to that of *Arcton 133*. [1]

For Examin Use

(iii) Suggest why hydrocarbons are replacing CFCs.

.....

.....[1]

(iv) Apart from cost, suggest **one** possible **disadvantage** of using a hydrocarbon instead of a CFC.

.....[1]

[Total : 10]

For Examiner's Use

3 This question refers to the hydrogen halides HF and HCl. Table 3.1 below lists some bond enthalpies which are required in different parts of this question.

Table 3.1

bond	bond enthalpy/kJ mol^{-1}
F—F	+158
H—H	+436
H—F	+568
H—Cl	+432

(a) Explain the term *bond enthalpy.*

.....

.....

.....[2]

(b) The hydrogen halides HCl and HF can be made from their elements. The formation of HCl is exothermic.

$$H_2(g) + Cl_2(g) \longrightarrow 2HCl(g) \qquad \Delta H = -184 \text{ kJ mol}^{-1}$$

(i) Calculate the bond enthalpy of the Cl—Cl bond.

[2]

(ii) Calculate the enthalpy change for the formation of HF from its elements:

$$\tfrac{1}{2}H_2(g) + \tfrac{1}{2}F_2(g) \longrightarrow HF(g)$$

[2]

For Examiner's Use

(c) When dissolved in water, HF acts as a weak acid whereas HCl acts as a strong acid.

(i) What is the difference between a weak acid and a strong acid?

.....

.....

.....[2]

(ii) Use the data in Table 3.1 to suggest why HF(aq) is a weaker acid than HCl(aq).

.....

.....

.....[2]

(iii) Write a balanced equation for the reaction between HCl(aq) and magnesium oxide, MgO(s).

.....[1]

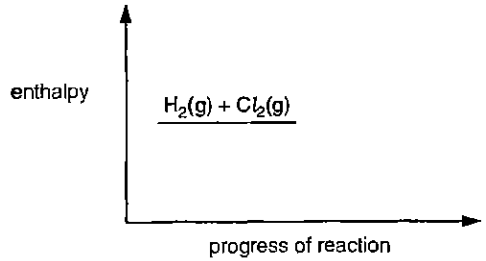
(d) The reaction between hydrogen and chlorine to form hydrogen chloride is exothermic. However, no reaction takes place unless the reactants are sparked or heated or exposed to light.

(i) Explain why this is so.

.....

.....[1]

(ii) Complete and label the enthalpy profile diagram below to support your answer in (d) (i).



[2]

[Total : 14]

For Examiner's Use

4 Ammonia, NH_3, is made industrially from its elements by the Haber process. This is an exothermic equilibrium reaction.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \qquad \Delta H = -92\,kJ\,mol^{-1}$$

(a) State **three** reaction conditions that are used in the Haber process.

.....

.....

.....[3]

(b) Describe and explain the effect of increasing the **pressure** on the **rate** of this reaction.

.....

.....

.....[2]

(c) Describe and explain how the **equilibrium position** of this reaction is affected by

(i) increasing the temperature,

.....

.....

.....[2]

(ii) increasing the pressure.

.....

.....

.....[2]

(d) Why is the temperature used described as a compromise?

.....

.....

.....[2]

(e) Some of the ammonia from the Haber process reacts with carbon dioxide to make the fertiliser urea.

$$\_\_NH_3(g) + \_\_CO_2(g) \longrightarrow \underset{\text{urea}}{\_\_NH_2CONH_2(s)} + \_\_H_2O(l)$$

(ii) Balance the above equation. [1]

(ii) Calculate the maximum mass of urea that could be obtained from 1.00 kg of ammonia.

[2]

[Total : 14]

In the following question, 1 mark is available for the quality of written communication.

5 Describe, with the aid of a diagram, how the Boltzmann distribution can help to explain the effect of temperature rises and the presence of catalysts on the rates of chemical reactions.

[Total : 7]

For Examiner's Use

Answer **all** questions.

1 **(a)** **(i)** Define the term *standard enthalpy change of formation.*

.....

.....

.....[2]

(ii) Write an equation, including state symbols, to represent the standard enthalpy change of formation of water.

.....[2]

(b) Hydrogen is obtained industrially from methane and water.

The overall process can be represented by the equation below.

$$CH_4(g) + 2H_2O(l) \longrightarrow CO_2(g) + 4H_2(g)$$

Use the following standard enthalpy changes of formation to calculate the enthalpy change of this reaction.

compound	$\Delta H_f^{\ominus}$/kJ mol^{-1}
$CH_4(g)$	–75
$H_2O(l)$	–286
$CO_2(g)$	–394

Answer ..... kJ mol^{-1} [3]

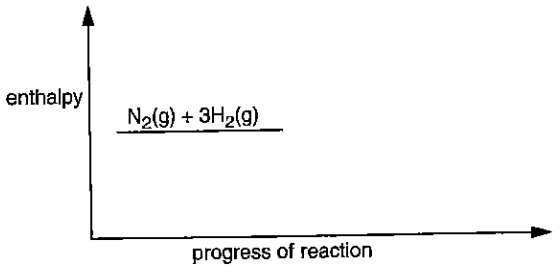
For Examiner's Use

(c) Hydrogen can be reacted with nitrogen in the presence of a catalyst to make ammonia in the Haber process.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \qquad \Delta H = -92\,kJ\,mol^{-1}$$

The activation energy for the **forward** reaction is +68 kJ mol^{-1}.

(i) Complete the enthalpy profile diagram below. Label clearly the enthalpy change of reaction and the activation energy.



[3]

(ii) Calculate the activation energy for the **reverse** reaction.

[1]

[Total : 11]

[Turn over

For Examiner's Use

2 Benzene, C_6H_6, can be manufactured by passing the gaseous hydrocarbon ethyne, C_2H_2, over finely divided nickel.

The equation is shown below.

$$3C_2H_2(g) \xrightarrow{\text{nickel}} C_6H_6(l) \qquad \textbf{reaction 2.1}$$

(a) Write a chemical equation, including state symbols, to represent the standard enthalpy change of combustion of benzene, $C_6H_6(l)$.

.....[2]

(b) Use the following standard enthalpy changes of combustion to calculate the standard enthalpy change for **reaction 2.1**.

compound	$\Delta H_c^{\ominus}$/kJ mol^{-1}
C_2H_2	–1301
C_6H_6	–3267

Answer ..... kJ mol^{-1} [3]

For Examiner's Use

(c) Suggest, with explanations, how the **rate of reaction 2.1** might be affected by

(i) an increase in temperature,

.....

.....

.....

.....[3]

(ii) an increase in pressure.

.....

.....

.....[2]

(d) Describe and explain the purpose of the nickel **in reaction 2.1.**

.....

.....

.....[2]

[Total : 12]

[Turn over

For Examiner's Use

3 When the indicator bromothymol blue (which can be represented by the formula HIn) dissolves in water the following dynamic equilibrium is set up.

$$\underset{\text{yellow}}{HIn(aq)} \rightleftharpoons \underset{\text{blue}}{In^-(aq)} + H^+(aq)$$

The indicator solution appears green because it contains both the yellow HIn and the blue In^- forms.

(a) State **two** features of a *dynamic equilibrium*.

.....

.....

.....[2]

(b) State le Chatelier's principle.

.....

.....

.....[2]

(c) Hydrochloric acid is added to the indicator solution above until no further colour change takes place.

Using le Chatelier's principle, suggest and explain what colour change you might see.

.....

.....

.....[2]

(d) Aqueous sodium hydroxide is gradually added to the resulting solution in **(c)** until no further colour changes take place.
Suggest **all** the colour changes you might see.
Explain your answer.

.....

.....

.....

.....

.....[4]

[Total : 10]

For Examiner's Use

4 One of the disadvantages of hard water is the limescale that accumulates inside kettles when water is boiled. This can be removed by a de-scaler. Commercial de-scalers contain a weak organic acid (which can be represented by the formula HA).

(a) Explain the difference between a *weak* acid and a *strong* acid.

.....

.....

.....

.....[2]

(b) The instructions for the use of a de-scaler are as follows.

Dissolve 10 g of the powder in enough water to cover the element of the kettle. Switch on the kettle until the water boils, then turn it off and leave to stand for 10 minutes. Empty out the contents and rinse thoroughly before use.

Limescale is calcium carbonate, $CaCO_3$.

(i) Write a balanced equation for the reaction between the organic acid, HA, and limescale.

.....[1]

(ii) Explain why heating the solution of the de-scaler increases its rate of reaction with limescale. Use collision theory and the concept of activation energy in your answer.

.....

.....

.....

.....[3]

[Total : 6]

[Turn over

For Examiner's Use

5 The question refers to the enthalpy changes of some reactions of hydrocarbons.
Table 5.1 below lists some average bond enthalpies.

Table 5.1

bond	bond enthalpy /kJ mol^{-1}
C–H	+413
C–C	+347
O–H	+464
C=O	+805
O=O	+498

(a) (i) Explain the term *average bond enthalpy.*

.....

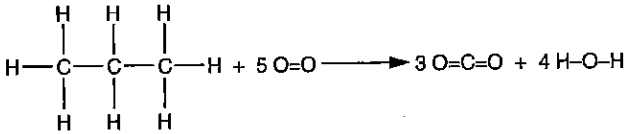
.....

.....[2]

(ii) Write an equation, including state symbols, to represent the average C–H bond enthalpy in methane, CH_4.

.....[2]

(b) Using the information in Table 5.1, calculate the enthalpy change of combustion of propane.



Answer ..... kJ mol^{-1} [3]

For Examiner's Use

(c) Table 5.2 shows the **actual** standard enthalpy changes of combustion of some alkanes.

Table 5.2

compound	molecular formula	$\Delta H_c^{\ominus}$/kJ mol^{-1}
propane	C_3H_8	–2220
butane	C_4H_{10}	–2870
pentane	C_5H_{12}	
hexane	C_6H_{14}	–4160

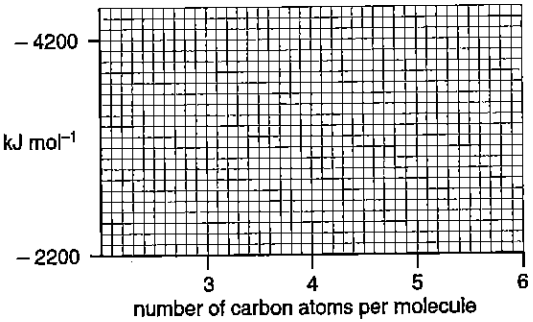
(i) Using average bond energies, the enthalpy change of combustion of butane was calculated as –2672 kJ mol^{-1}. The **actual** value for butane is shown in Table 5.2.

Suggest a reason for the difference.

.....

.....[1]

(ii) Plot a graph below using the data in Table 5.2.



[1]

(iii) Use your graph to determine a value for the standard enthalpy change of combustion of pentane.

..... kJ mol^{-1} [1]

(iv) Suggest why there is a regular trend in $\Delta H_c^{\ominus}$ for the alkanes.

.....

.....[1]

[Total : 11]

[Turn over

For Examiner's Use

In this question, 1 mark is available for the quality of written communication.

6 **(a)** Explain how a car's catalytic converter works, describing what type of catalysis is shown here.

.....

.....

.....

.....

.....

.....

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.....

.....

.....[6]

(b) Why is the Haber process so important for mankind?

.....

.....

.....

.....

.....

.....[4]

[Total : 10]

Exi

Answer **all** the questions.

1 **(a)** The formation of compounds is accompanied by enthalpy changes.

(i) Explain the term *standard enthalpy change of formation.*

.....

.....

..... [2]

(ii) State the conditions under which standard enthalpy changes are measured.

.....

..... [2]

(b) Oxidation reactions are normally exothermic.

(i) What do you understand by the term *exothermic*?

..... [1]

(ii) State **one** example of an exothermic oxidation reaction that is important in industry or everyday life.

..... [1]

(c) The oxidation of hydrazine, N_2H_4, by dinitrogen tetroxide, N_2O_4, has been used in rocket propulsion.

$$2N_2H_4(l) + N_2O_4(l) \longrightarrow 3N_2(g) + 4H_2O(g)$$

(i) Use the following standard enthalpy changes of formation to calculate the enthalpy change for this reaction.

compound	$\Delta H_f^{\ominus}$/kJ mol^{-1}
$N_2H_4(l)$	+51
$N_2O_4(l)$	+9
$H_2O(g)$	−242

Answer ..... kJ mol^{-1} [3]

(ii) Suggest what feature, other than the value of ΔH, makes this reaction suitable for propelling a rocket.

..... [1]

[Total : 10]

2 Photosynthesis is an endothermic reaction.

(a) Under what temperature conditions do most endothermic reactions occur?

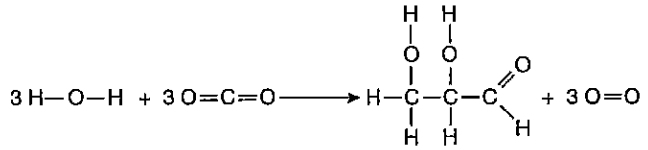
..... [1]

(b) Plants photosynthesise well both in the Tropics and under Arctic conditions.

Why is this?

..... [1]

(c) One of the products of photosynthesis is glyceraldehyde, $C_3H_6O_3$. Equation 2.1 shows the formation of glyceraldehyde.



glyceraldehyde **Equation 2.1**

Table 2.1 lists relevant average bond enthalpies.

Table 2.1

bond	bond enthalpy / kJ mol^{-1}
O=O	+498
O—H	+464
C=O	+750
C—O	+358
C—H	+413
C—C	+347

For Examiner Use

Use these bond enthalpies to calculate the following quantities:

(i) the total enthalpy of all the bonds on the **left** hand side of Equation 2.1,

[2]

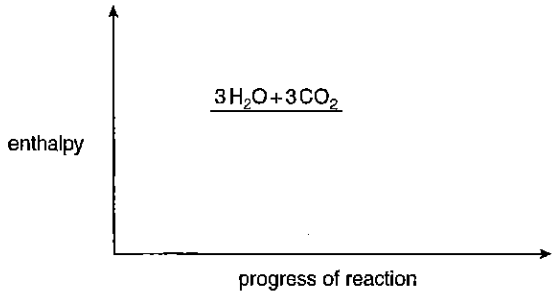
(ii) the total enthalpy of all the bonds on the **right** hand side of Equation 2.1,

[2]

(iii) hence, the enthalpy change for the reaction in Equation 2.1. Include the sign of ΔH in your answer.

ΔH = ... kJ mol^{-1} [1]

(d) Complete the following enthalpy profile diagram to show your calculated ΔH for the reaction in Equation 2.1.



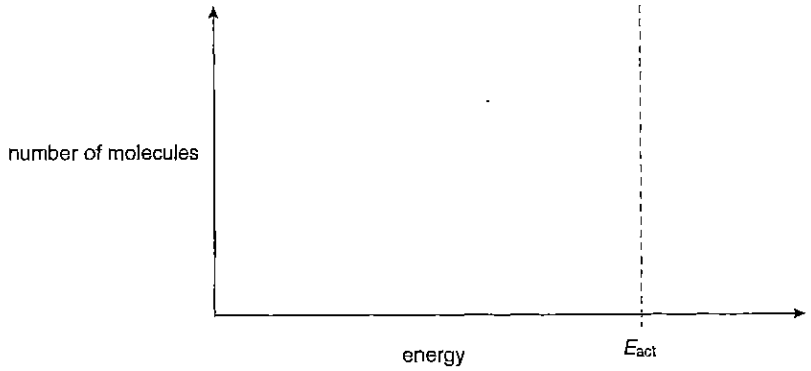
[1]

[Total : 8]

Ex

3 **(a)** **(i)** On the following axes, sketch the Boltzmann distribution of molecular energies for a fixed amount of gas at a temperature labelled as T_1.

E_{act} represents the activation energy of the reaction.



[2]

(ii) On the same axes, sketch another distribution for the *same* amount of gas, at a higher temperature, labelled as T_2.

[2]

(b) What do you understand by the term *activation energy*, E_{act}?

.....

..... [1]

(c) Using your answers to **(a)** and **(b)**, explain why the rate of a chemical reaction is affected by changes in temperature.

.....

.....

.....

..... [3]

(d) Table 3.1 lists some average bond enthalpies.

Table 3.1

bond	bond enthalpy /kJ mol^{-1}
C—H	+413
C—Cl	+327
Cl—Cl	+243
Br—Br	+193

(i) Use the values in Table 3.1 to suggest the order of **increasing** E_{act} values for the following four reactions. Write the letters A, B, C and D in the appropriate boxes.

A $CH_4 \longrightarrow CH_3 + H$

B $CH_3 + Cl \longrightarrow CH_3Cl$

C $Br_2 \longrightarrow 2Br$

D $Cl_2 \longrightarrow 2Cl$

[ ] < [ ] < [ ] < [ ] [2]

smallest E_{act} largest E_{act}

(ii) Explain your choice of order in **(i)**.

.....

.....

..... [2]

[Total : 12]

4 The equation below shows the first stage in the industrial manufacture of nitric acid from ammonia.

$4NH_3(g) + 5O_2(g) \rightleftharpoons 4NO(g) + 6H_2O(g)$ $\Delta H = -907$ kJ mol^{-1} **Reaction 4.1**

This reaction is catalysed by a platinum-rhodium gauze at 800 °C.

(a) State and explain what effect a catalyst has on a reaction.

.....

.....

.....

..... [3]

(b) What *type* of catalyst is the platinum-rhodium gauze?

..... [1]

(c) This reaction is an example of a *dynamic equilibrium.*

State **two** features of a dynamic equilibrium.

.....

.....

..... [2]

(d) (i) State le Chatelier's principle.

.....

..... [2]

(ii) Use le Chatelier's principle to describe and explain how the **equilibrium position** of Reaction 4.1 is affected by increasing the pressure and by increasing the temperature.

increasing the pressure

.....

.....

.....

increasing the temperature

.....

.....

..... [4]

(e) Suggest a reason why the reaction is carried out at 800 °C.

.....

..... [1]

[Total : 13]

5 This question is about the reactions of acids.

(a) Sulphuric acid reacts with ammonia to give ammonium sulphate.

$$2NH_3 + H_2SO_4 \longrightarrow (NH_4)_2SO_4$$

(i) What property of ammonia is shown in this reaction?

..... [1]

(ii) Calculate the maximum mass of ammonium sulphate that can be obtained from 100 g of ammonia.

[A_r: H, 1.0; N, 14.0; O, 16.0; S, 32.1]

mass = ... g [3]

(iii) State a large scale use of ammonium sulphate.

..... [1]

(b) State what you would observe on adding nitric acid to magnesium carbonate. Write a balanced equation for the reaction.

Observation(s)

.....

.....

Equation

.....

[3]

[Total : 8]

In this question, 1 mark is available for the quality of written communication.

6 Part of the Earth's atmosphere is damaged by the presence of CFCs.
State which component of the atmosphere CFCs affect, and describe in detail how this damage is caused.

[Total : 9]

Answer **all** questions.

1 The enthalpy change for the reaction between hydrochloric acid, HCl(aq), and sodium hydroxide, NaOH(aq), can be determined in the following way.

- 50.0 cm^3 of 2.00 mol dm^{-3} HCl(aq) is placed in a plastic cup, and its temperature recorded.
- 50.0 cm^3 of 2.00 mol dm^{-3} NaOH(aq) is placed in another plastic cup, and its temperature recorded.
- The two solutions are mixed with stirring, and the final temperature recorded.

The following results were obtained from one such experiment:

initial temperature of both HCl(aq) and NaOH(aq) = 18.0 °C

final temperature after mixing = 31.9 °C

(Take the specific heat capacity of all solutions to be 4.18 J g^{-1} K^{-1}, and the densities of all solutions to be 1.00 g cm^{-3}.)

(a) Calculate the heat evolved in the above experiment. Include units in your answer.

heat evolved = ... [3]

(b) Calculate how many moles of HCl were used.

moles of HCl = ... [1]

(c) Hence calculate the enthalpy change, in kJ, for the reaction of 1 mol of HCl with 1 mol of NaOH.

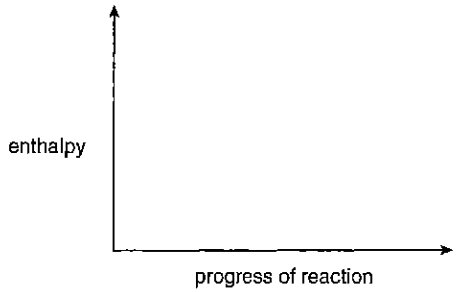
enthalpy change = ... kJ [1]

[Total : 5]

2 On heating in a lime kiln at 1000 °C, limestone decomposes according to the following equation.

$$CaCO_3(s) \longrightarrow CaO(s) + CO_2(g) \qquad \Delta H = +178\,kJ\,mol^{-1}$$

(a) Using the axes below, sketch the enthalpy profile of this reaction. Label the activation energy E_A and the enthalpy change ΔH.



[3]

(b) Suggest **two** reasons why this reaction needs heating to a high temperature.

1. .....

.....

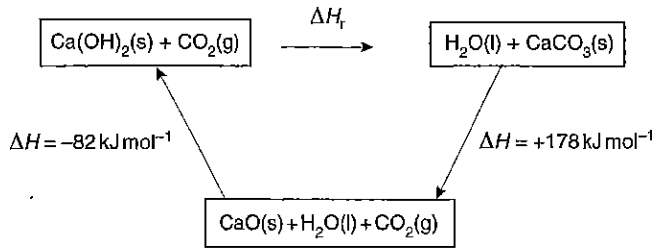
2. .....

..... [2]

(c) When water is added to calcium oxide, CaO, it becomes 'slaked' to give calcium hydroxide, $Ca(OH)_2$.

$$CaO(s) + H_2O(l) \longrightarrow Ca(OH)_2(s) \qquad \Delta H = -82\,kJ\,mol^{-1}$$

Calculate the enthalpy change ΔH_r in the following cycle.



ΔH_r = ... kJ mol^{-1} [2]

[Total : 7]

3 The chlorination of methane in the gas phase involves the following two steps.

$CH_4 + Cl \longrightarrow CH_3 + HCl$ **reaction 3.1**

$CH_3 + Cl_2 \longrightarrow CH_3Cl + Cl$ **reaction 3.2**

Table 3.1 lists some relevant average bond enthalpies.

Table 3.1

bond	bond enthalpy / kJ mol^{-1}
C—H	+413
C—Cl	+327
H—Cl	+432
Cl—Cl	+243

(a) **(i)** Use these bond enthalpies to calculate the enthalpy changes of reactions **3.1** and **3.2**.

reaction 3.1

Answer ..... kJ mol^{-1}

reaction 3.2

Answer ..... kJ mol^{-1} [2]

(ii) Suggest which might be the faster of these two reactions. Give a reason for your answer.

.....

..... [1]

(b) An alternative reaction route has been suggested for this reaction, which involves the following two steps.

$CH_4 + Cl \longrightarrow CH_3Cl + H$ **reaction 3.3**

$H + Cl_2 \longrightarrow HCl + Cl$ **reaction 3.4**

Use Table 3.1 to suggest why this reaction route is unlikely to take place.

.....

.....

..... [2]

[Total : 5]

4 It has been suggested that using methane, CH_4, as a fuel for cars rather than petrol would decrease the amount of carbon dioxide produced per mile. This question looks at how much this reduction in CO_2 emission might be. You may assume that petrol is pure octane, C_8H_{18}.

The combustion of methane can be represented by the following equation.

$$CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O \qquad \Delta H_c^{\ominus} = -890\ kJ\ mol^{-1}$$

(a) Balance the following equation for the combustion of octane.

$$C_8H_{18} + ...O_2 \longrightarrow .....CO_2 + ... H_2O \qquad [1]$$

(b) The enthalpy change of combustion, $\Delta H_c^{\ominus}$, of octane is –5472 kJ per mole of octane.

Use your balanced equation and the given $\Delta H_c^{\ominus}$ data to calculate for each fuel:

(i) the enthalpy change **per mole of CO_2 produced**, and hence

(ii) the number of moles of CO_2 produced per kJ of heat energy given out.

Write your answers in the Table below.

fuel	$\Delta H_c^{\ominus}$ per mole of alkane burned/kJ	$\Delta H_c^{\ominus}$ per mole of CO_2 produced/kJ	moles of CO_2 produced per kJ of heat given out
methane	–890		
octane	–5472		

[4]

(iii) Hence calculate a value for the ratio:

$$\frac{\text{moles of } CO_2 \text{ produced per kJ from methane}}{\text{moles of } CO_2 \text{ produced per kJ from octane}}$$

Ratio ..... [1]

(c) Both methane and octane undergo incomplete combustion in a car engine. As a result of this, unburned hydrocarbons and carbon monoxide, CO, occur in the exhaust gases. Nitrogen monoxide, NO, is also formed inside the engine. All three pollutants can be removed by fitting a catalytic converter to the exhaust system.

(i) State **one** environmental consequence of **each** of the following emissions.

unburned hydrocarbons

.....

CO

.....

NO

..... [3]

(ii) How is the NO formed in a car engine?

.....

..... [1]

(iii) NO and CO react together on the surface of the catalyst. Write an equation for this reaction.

..... [1]

(iv) What is the catalyst made of?

..... [1]

(v) The catalyst is a heterogeneous catalyst. What is the meaning of *heterogeneous*?

.....

..... [1]

(vi) The catalytic converter is positioned as close to the engine as possible, so that it heats up quickly. Why does the converter work best when it is hot?

.....

..... [1]

[Total : 14]

5 Methanol is an important industrial organic chemical. It is used as a solvent and a feedstock for the manufacture of several other compounds such as ethanoic acid. A two-stage process to make methanol from natural gas, methane, is summarised in the following equations.

reaction 5.1 $CH_4(g) + H_2O(g) \xrightleftharpoons{\text{Ni at 700 °C}} CO(g) + 3H_2(g)$ $\Delta H = +207\ kJ\ mol^{-1}$

reaction 5.2 $CO(g) + 2H_2(g) \xrightleftharpoons{\text{Cr at 300 °C and 30 MPa}} CH_3OH(g)$ $\Delta H = -129\ kJ\ mol^{-1}$

(a) Describe and explain the effect of increasing the pressure on the **rate** of reaction 5.1.

.....

.....

..... [2]

(b) Describe and explain how the **equilibrium position** of reaction 5.1 is affected by

(i) increasing the temperature,

.....

.....

..... [2]

(ii) increasing the pressure.

.....

.....

..... [2]

(c) Reaction 5.2 uses the products from reaction 5.1. Suggest a reason why these two reactions cannot proceed one after the other in the same reaction vessel.

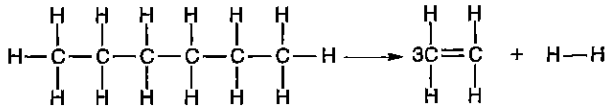
.....

..... [1]

[Total : 7]

Answer **all** the questions.

1 Ethene is an important industrial chemical, used to make plastics, solvents and antifreeze. It is usually made by cracking larger alkanes. The equation for a cracking reaction is shown below.



reaction 1.1

(a) (i) Define the term *average bond enthalpy.*

.....

.....

..... [2]

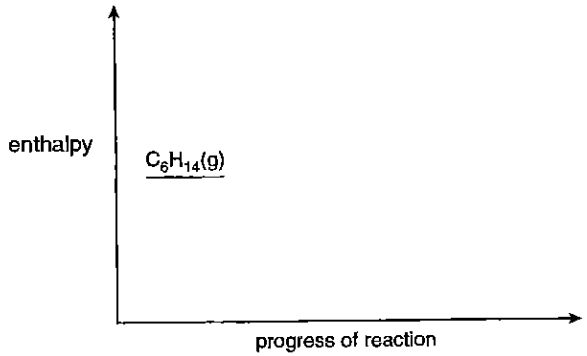
(ii) Use the average bond enthalpies in Table 1.1 to calculate the standard enthalpy change, $\Delta H_r^{\ominus}$, for reaction 1.1.

Table 1.1

bond	average bond enthalpy / kJ mol^{-1}
H—H	436
C—H	410
C—C	350
C=C	610

$\Delta H_r^{\ominus}$ = ... kJ mol^{-1} [3]

(b) Complete the enthalpy profile diagram for reaction 1.1.



[3]

[Total: 8]

For Examiner's Use

2 The first stage in the industrial production of nitric acid from ammonia can be represented by the following equation.

$$4NH_3(g) + 5O_2(g) \rightleftharpoons 4NO(g) + 6H_2O(g)$$

(a) Use the following standard enthalpy changes of formation to calculate the enthalpy change, $\Delta H_r^{\ominus}$, for this reaction.

compound	$\Delta H_f^{\ominus}$ / kJ mol^{-1}
$NH_3(g)$	–46
$NO(g)$	+90
$H_2O(g)$	–242

$\Delta H_r^{\ominus}$ = ... kJ mol^{-1} [3]

(b) **(i)** State le Chatelier's principle.

.....

.....

..... [2]

(ii) Predict and explain how the **equilibrium position** of this reaction is affected by increasing the pressure.

.....

.....

..... [2]

For Examiner's Use

(c) This reaction takes place as the gases are passed slowly through a fine gauze made of a platinum-rhodium alloy.

(i) State the purpose of the platinum-rhodium gauze.

..... [1]

(ii) Suggest why the gases have to be passed through the gauze **slowly**.

..... [1]

(d) The NO produced is reacted with oxygen and water to give nitric acid, HNO_3.

Construct a balanced equation for this reaction.

..... [2]

[Total: 11]

[Turn over

For Examiner's Use

3 When carbon dioxide dissolves in water, the following dynamic equilibria are set up.

$$CO_2(g) + aq \rightleftharpoons CO_2(aq)$$

$$CO_2(aq) + H_2O(l) \rightleftharpoons H^+(aq) + HCO_3^-(aq)$$

(a) State **two** features of a dynamic equilibrium.

.....

.....

..... [2]

(b) Use the above equations and your understanding of dynamic equilibrium to explain the following observations.

(i) Bubbling carbon dioxide into an aqueous solution of universal indicator turns its colour from green to orange.

.....

.....

..... [2]

(ii) A saturated solution of carbon dioxide effervesces when a small amount of concentrated sulphuric acid is added to it.

.....

.....

..... [2]

[Total: 6]

For Examiner's Use

4 Reactions can be speeded up either by increasing the concentration of reagents or by increasing the temperature.

(a) Explain why an increase in concentration increases the rate of a reaction.

.....

.....

..... [2]

(b) The diagram in Fig. 4.1 shows the energy distribution of reactant molecules at a temperature T_1. E_a represents the activation energy of the reaction.

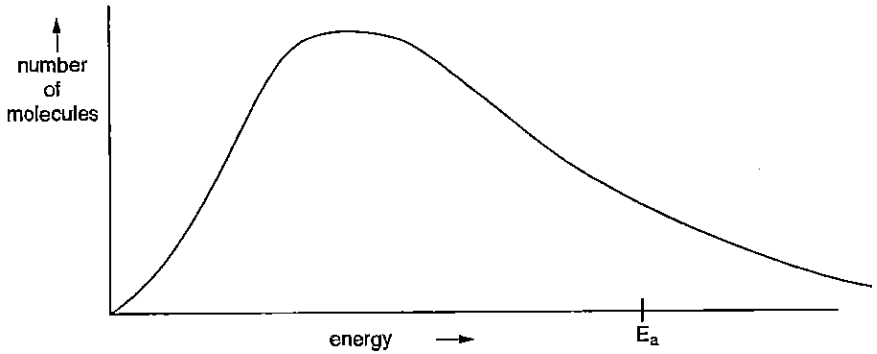


Fig. 4.1

(i) Draw a second curve on Fig. 4.1 to represent the energy distribution of the same number of molecules at a higher temperature. Label your curve T_2. [2]

(ii) Use your curve to explain how an increase in temperature can cause an increase in the rate of a reaction.

.....

.....

.....

..... [2]

[Total: 6]

[Turn over

For Examiner's Use

5 Sulphuric acid, H_2SO_4, is a strong acid which is an important industrial and laboratory chemical.

(a) Spillages of sulphuric acid can be made harmless by neutralisation with sodium carbonate solution, $Na_2CO_3(aq)$.

(i) State what you would see during this neutralisation reaction.

.....

..... [1]

(ii) Write a balanced equation for this reaction.

..... [2]

(b) Sulphuric acid reacts with ammonia in the manufacture of the salt ammonium sulphate, $(NH_4)_2SO_4$.

(i) State the role of ammonia in this reaction.

..... [1]

(ii) Calculate the percentage by mass of nitrogen in ammonium sulphate.

[2]

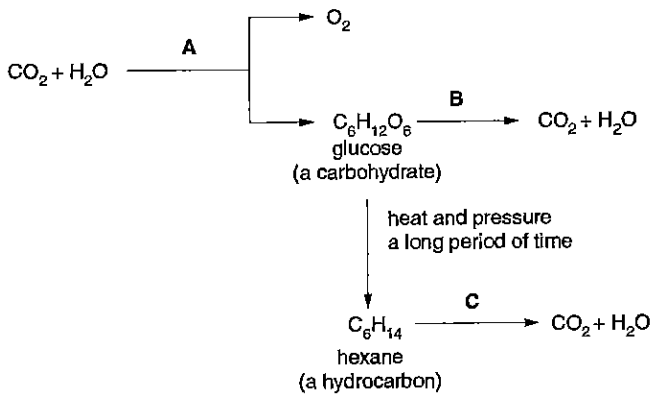
(iii) State a **large scale** use of ammonium sulphate.

..... [1]

[Total: 7]

For Examiner's Use

6 The following chart shows some processes involving carbohydrate and hydrocarbon fuels.



Discuss the processes **A**, **B** and **C** under the following headings. In your answer refer to:

- the name of each process
- the situations in which each occurs
- their endothermic or exothermic nature

How do these processes illustrate the statement that 'most fuels are solar fuels, since their energy has originally come from the sun'?

..... [7]

[Total: 7]

For Examiner's Use

Answer **all** the questions.

1 Ammonia is manufactured by the Haber process according to the following equation.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \qquad \Delta H^{\ominus} = -92\,kJ\,mol^{-1}$$

(a) State the temperature used in this industrial process.

.....[1]

(b) The temperature used is often described as a 'compromise' or an 'optimum' temperature.

What would be the main **disadvantage** of using

(i) a lower temperature

.....

.....[1]

(ii) a higher temperature?

.....

.....[1]

(c) A few years ago some Haber process plants were designed to run at extremely high pressures, but now these have mostly been closed down.

(i) Suggest one **advantage** of running a plant at a very high pressure.

.....

.....[1]

(ii) Suggest one **disadvantage** of running a plant at a very high pressure.

.....

.....[1]

(d) Under the conditions usually employed, the yield of ammonia is between 10% and 15%.

Suggest what happens to the unreacted nitrogen and hydrogen in the Haber plant.

.....[1]

(e) State two **large scale** uses of ammonia.

.....

.....[2]

[Total: 8]

For Examiner's Use

2 In the vapour state, sulphur dichloride, SCl_2, undergoes the following equilibrium reaction.

$$2\,Cl{-}S{-}Cl(g) \rightleftharpoons Cl{-}S{-}S{-}Cl(g) + Cl{-}Cl(g) \qquad \textbf{reaction 2.1}$$

(a) State **two** characteristics of a dynamic equilibrium.

1 .....

.....

2 .....

.....[2]

(b) Use the following average bond enthalpies to calculate the standard enthalpy change, $\Delta H_r^{\ominus}$, for the forward reaction 2.1.

bond	average bond enthalpy / kJ mol^{-1}
Cl—Cl	242
S—Cl	255
S—S	266

$\Delta H_r^{\ominus}$ = ...kJ mol^{-1} [3]

(c) Describe how the position of equilibrium might be affected by an increase in temperature. Explain your answer.

.....

.....

.....[2]

[Total: 7]

[Turn over

For Examiner's Use

3 The standard enthalpy changes of formation of hydrocarbons are difficult to measure directly by experiment, but they can be calculated from standard enthalpy changes of combustion by using Hess's Law.

Table 3.1 lists some standard enthalpy changes of combustion of some relevant substances.

Table 3.1

substance	$\Delta H_c^{\ominus}$ / kJ mol^{-1}
$C_3H_8(g)$	–2220
C(s)	–394
$H_2(g)$	–286

(a) (i) Define the term *standard enthalpy change of combustion.*

.....

.....

.....

.....[3]

(ii) Write a balanced equation, including state symbols, to represent the standard enthalpy change of combustion of propane, C_3H_8.

.....[2]

For Examiner's Use

(b) The equation that represents the standard enthalpy change of formation, $\Delta H_f^{\ominus}$, of propane is shown below.

$$3C(s) + 4H_2(g) \longrightarrow C_3H_8(g)$$

(i) Suggest a reason why $\Delta H_f^{\ominus}$ of propane is difficult to determine directly.

.....

.....[1]

(ii) Use Hess's law and the data in Table 3.1 to calculate a value of $\Delta H_f^{\ominus}$ for propane.

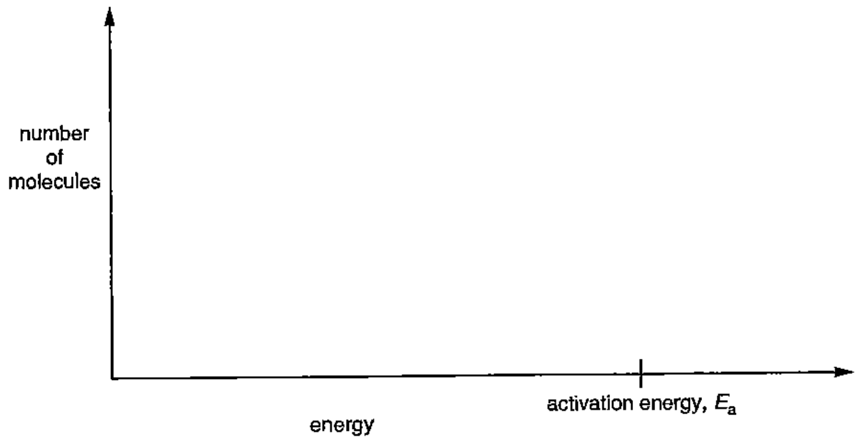
$\Delta H_f^{\ominus}$ = ...kJ mol^{-1} [3]

[Total: 9]

[Turn over

For Examiner's Use

4 (a) (i) On the following axes, sketch the Boltzmann distribution of molecular energies for a fixed amount of gas at a particular temperature.



[2]

Fig. 4.1

(ii) What is meant by the term *activation energy*?

....

.... [1]

(iii) Mark on Fig. 4.1 a possible activation energy in the presence of a catalyst. Label this E_a(cat). [1]

For Examiner's Use

(b) In this question, one mark is available for the quality of written communication.

Explain how a catalyst speeds up a reaction. Use ideas from part **(a)** in your explanation.

Catalysts are of two types, *homogeneous* and *heterogeneous*. Explain the two terms in italics. Give an example of each type of catalyst and write an equation for the reaction it catalyses.

....

.... [7]

Quality of Written Communication [1]

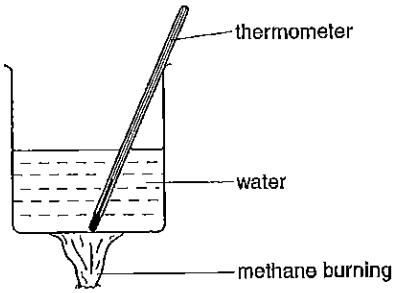
[Total: 12]

[Turn over

Answer **all** the questions.

1 Alkanes, such as methane, can be used as fuels.

In an experiment to determine its enthalpy change of combustion, methane, CH_4, was burnt in air.



In the experiment, 150 g of water were used. The temperature of the water changed from 19.5 °C to 61.5 °C when 0.600 g of methane was burnt.

(a) Write the equation for the complete combustion of methane.

.....[1]

(b) Calculate the energy gained by the water, in kJ.

The specific heat capacity of water is $4.18\,J\,g^{-1}\,K^{-1}$.

energy = ... kJ [2]

(c) How many moles of methane were burnt in the experiment?

answer = ... mol **[1]**

(d) Calculate the enthalpy change of combustion, in $kJ\,mol^{-1}$, of methane.

enthalpy change of combustion = ... $kJ\,mol^{-1}$ [2]

[Total: 6]

2 The energy needed to propel a rocket away from Earth is produced by burning a fuel in oxygen.

(a) Hydrazine, N_2H_4, is a liquid that has been used as a rocket fuel. It reacts with oxygen as shown below.

$$N_2H_4(l) + O_2(g) \longrightarrow N_2(g) + 2H_2O(g)$$

Hess's Law can be used to find the enthalpy change for this reaction using enthalpy changes of formation, ΔH_f.

(i) State Hess's Law.

.....

.....

.....[1]

(ii) Write the equation, including state symbols, for the standard enthalpy change of formation of hydrazine.

.....[1]

(iii) The table below shows some enthalpy changes of formation.

compound	ΔH_f /kJ mol^{-1}
$N_2H_4(l)$	+51
$H_2O(g)$	−241

Calculate the enthalpy change for the combustion of hydrazine.

$$N_2H_4(l) + O_2(g) \longrightarrow N_2(g) + 2H_2O(g)$$

enthalpy change of combustion = ... $kJ\,mol^{-1}$ [3]

(iv) Suggest and explain why using hydrazine as a rocket fuel may be 'environmentally friendly'.

.....

.....[1]

[Turn over

(b) A rocket could be sent to Mars. It has been suggested that methane could be made on Mars. The methane could be used to provide the fuel to bring the rocket back to Earth.

The atmosphere of Mars contains carbon dioxide and this can react with hydrogen to produce methane as shown below.

$$CO_2(g) + 4H_2(g) \rightleftharpoons CH_4(g) + 2H_2O(g) \quad \textbf{equation 2.1}$$

(i) **Equation 2.1** shows a reaction in dynamic equilibrium.

State **two** features of a dynamic equilibrium.

1 .....

.....

2 .....

.....[2]

(ii) The table below shows some average bond enthalpies.

bond	average bond enthalpy/kJ mol^{-1}
C=O	805
H—H	436
C—H	413
O—H	464

Calculate the enthalpy change for the forward reaction in **equation 2.1.**

enthalpy change = ... kJ mol^{-1} [3]

(iii) Suggest what conditions of temperature and pressure should be used to give a high equilibrium yield of methane in **equation 2.1.** Give your reasoning.

temperature .....

.....

.....

pressure .....

.....

.....[4]

[Total: 15]

3 This question is concerned with the reactions of acids.

(a) Define an acid.

.....[1]

(b) The table below gives data about some solid compounds of copper and sodium. Use the data to help to answer the questions in **(i)** and **(iii)**.

compound	formula	colour	solubility in water	colour in solution
copper(II) oxide	CuO	black	insoluble	—
copper(II) chloride	$CuCl_2$	yellow	soluble	blue/green
copper(II) carbonate	$CuCO_3$	green	insoluble	—
sodium chloride	NaCl	white	soluble	colourless
sodium carbonate	Na_2CO_3	white	soluble	colourless

(i) Write equations, including state symbols, for the following reactions of hydrochloric acid.

copper(II) oxide and hydrochloric acid

.....

sodium carbonate and hydrochloric acid.

.....[3]

(ii) The reaction between copper(II) oxide and hydrochloric acid is very slow at room temperature and is therefore usually heated.

Suggest a reason why this reaction is so slow at room temperature.

.....

.....[1]

(iii) What would you expect to **see** when copper(II) carbonate reacts with hydrochloric acid?

.....

.....

.....[2]

4 In the 19th century the Swedish chemist Berzelius first gave the name 'catalyst' to a substance that increases the rate of chemical reactions. Nowadays heterogeneous catalysts are important in a variety of industrial processes and in everyday life.

Describe the importance of heterogeneous catalysts in industrial processes or in everyday life. In your answer you should:

- explain, in terms of particles, how a catalyst increases the rate of a reaction;
- draw a labelled enthalpy profile diagram for an uncatalysed reaction and for the same reaction when catalysed;
- name **two** heterogeneous catalysts used in industrial processes or in everyday life – in each case write an equation for the reaction that they catalyse;
- explain how a heterogeneous catalyst works.

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[Total: 12]

END OF QUESTION PAPER

Answer **all** the questions.

1 Reactions that release energy are essential to maintain many aspects of everyday life.

(a) Enthalpy changes can be calculated using average bond enthalpies. **Table 1.1** shows some average bond enthalpies.

Table 1.1

bond	average bond enthalpy/ kJ mol^{-1}
C—C	+347
C—H	+413
O—H	+464
O=O	+498
C=O	+805
C—O	+358

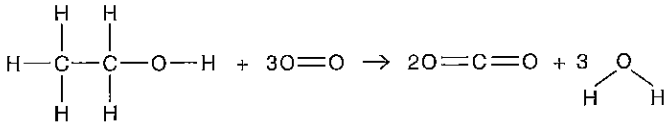
(i) Define the term *bond enthalpy*.

.....

.....

.....[2]

(ii) Ethanol, C_2H_5OH, can be burnt to release energy. The equation below shows the combustion of ethanol.



Use the data in **Table 1.1** to calculate a value for the enthalpy change of combustion of gaseous ethanol, ΔH_c.

ΔH_c = ... kJ mol^{-1} [3]

(b) Glucose, $C_6H_{12}O_6$, can also be oxidised.

The table below shows some enthalpy changes of formation, ΔH_f.

compound	ΔH_f/ kJ mol^{-1}
$C_6H_{12}O_6(s)$	–1273
$CO_2(g)$	–394
$H_2O(l)$	–286

(i) Use the data to calculate the enthalpy change of combustion, ΔH_c, for glucose.

$$C_6H_{12}O_6(s) + 6O_2(g) \rightarrow 6CO_2(g) + 6H_2O(l)$$

ΔH_c = ... kJ mol^{-1} [3]

(ii) What name is given to this process of energy release when it occurs in a living species?

.....[1]

[Total: 9]

2 Many chemical reactions are reversible and are able to form equilibrium mixtures.

Hydrogen and iodine react together to form hydrogen iodide in a reversible reaction.

$$\underset{\text{colourless}}{H_2(g)} + \underset{\text{purple}}{I_2(g)} \rightleftharpoons \underset{\text{colourless}}{2HI(g)} \quad \Delta H = +53 \text{ kJ mol}^{-1}$$

(a) Explain the following observations when changes are made to an equilibrium mixture of $H_2(g)$, $I_2(g)$ and $HI(g)$.

Include reference to the equilibrium position and any other factors.

(i) When the temperature is increased the purple colour becomes paler.

.....

.....

.....[2]

(ii) When the pressure is increased the purple colour becomes deeper.

.....

.....

.....

.....[3]

(b) The **rate** at which equilibrium is reached could be increased by increasing the temperature or pressure.

In each case explain why the rate increases:

(i) on increasing the temperature,

.....

.....

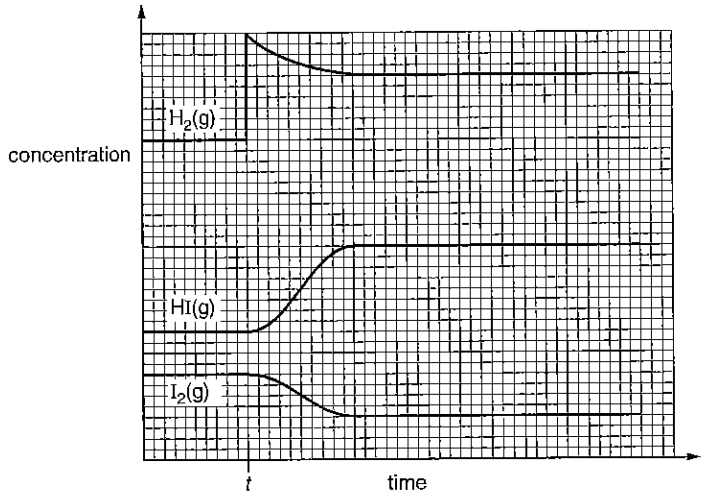
.....[2]

(ii) on increasing the pressure.

.....

.....[1]

(c) $H_2(g)$, $I_2(g)$ and HI(g) were mixed together and allowed to reach equilibrium. The concentrations of the gases were then measured at various times and the results plotted. At time *t*, a change was made to the composition of the mixture.



(i) What change was made to the mixture at time *t*?

.....[1]

(ii) Explain the changes that happen to the equilibrium mixture after time *t*.

.....

.....

.....

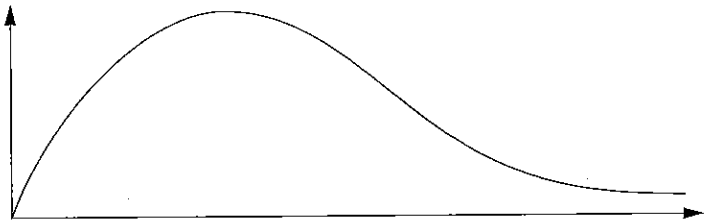
.....[2]

[Total: 11]

3 This question is concerned with some of the graphs you may have seen in your studies.

(a) **Graph A** shows a Boltzmann distribution.

Graph A



(i) Label the axes on **graph A**. [2]

(ii) Explain, using **graph A**, the effect of adding a catalyst on the reaction rate.

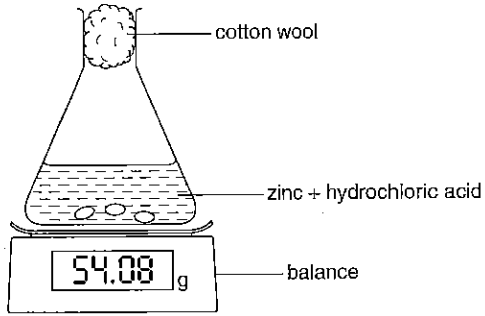
Include labelled lines of the energies involved on **graph A**.

.....

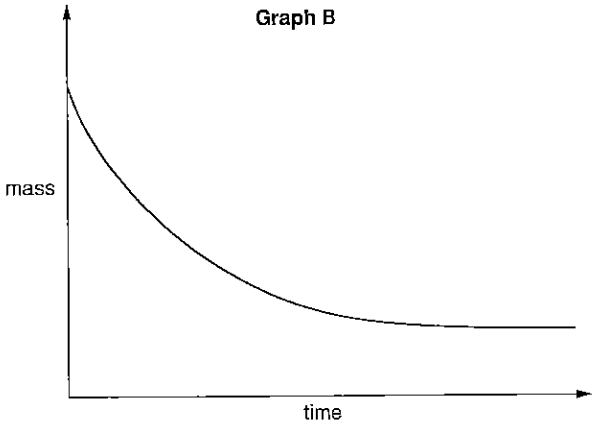
.....

.....[2]

(b) **Graph B** shows the change in mass observed in an experiment used to investigate the rate of a reaction.



Graph B



(i) Suggest what is happening in this experiment to produce the loss of mass with time.

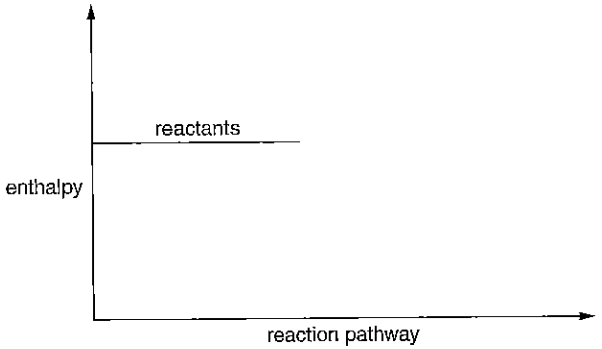
.....[1]

(ii) Exactly the same experiment was repeated but with a catalyst added.

On **graph B** sketch the line that would be produced in the presence of the catalyst. [2]

(c) The forward direction of a reversible reaction has an enthalpy change of reaction, ΔH, of $-120\,kJ\,mol^{-1}$ and an activation energy, E_a, of $250\,kJ\,mol^{-1}$.

(i) On the axes below, complete the enthalpy profile diagram for this reaction. [2]



(ii) On your diagram label ΔH and E_a. [2]

(iii) Use your diagram to calculate E_a for the reverse reaction. [1]

E_a = ... $kJ\,mol^{-1}$

[Total: 12]

Answer **all** the questions.

1 Students carried out an experiment to investigate the rate of a reaction.

The students added dilute hydrochloric acid to marble chips. They collected the gas and measured the volume, at regular intervals, until the reaction was complete.

They obtained the graph shown in **Fig. 1.1** below.

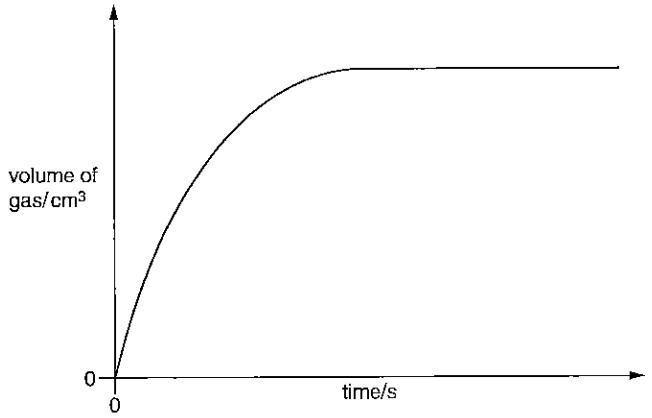


Fig. 1.1

(a) (i) How does the rate of reaction change as the reaction proceeds?

.....[1]

(ii) Explain the changes in the rate of the reaction in terms of collisions.

.....

.....

.....

.....

.....[2]

(b) The experiment was repeated using crushed marble in place of the marble chips.

On **Fig. 1.1**, sketch the graph the students obtained from this experiment. The quantities and the temperature remain the same. **[2]**

[Total: 5]

2 Bond enthalpies can be used to calculate enthalpy changes of reactions. Some bond enthalpies are given in **Table 2.1**.

bond	bond enthalpy/kJ mol^{-1}
Cl–Cl	+242
H–H	+436
H–F	+568
H–Cl	+432

Table 2.1

(a) (i) Define the term *bond enthalpy*.

.....

.....

.....[2]

(ii) Why is the sign of bond enthalpy positive?

.....

.....[1]

(b) Hydrogen halides can be made from their elements.

Although the reaction between hydrogen and fluorine is explosive, the enthalpy change for the reaction can be found.

$$H_2(g) + F_2(g) \longrightarrow 2HF(g) \qquad \Delta H = -542\,kJ\,mol^{-1}$$

Use this value of the enthalpy change for the reaction, and the data in **Table 2.1**, to calculate the bond enthalpy of the F–F bond.

bond enthalpy of the F–F bond = ... kJ mol^{-1} **[3]**

(c) Use the data in **Table 2.1** to calculate the enthalpy change of formation of hydrogen chloride, HCl.

enthalpy change of formation of HCl = ... $kJ\,mol^{-1}$ **[2]**

(d) Hydrogen fluoride and hydrogen chloride dissolve in water to give hydrofluoric acid and hydrochloric acid. Hydrofluoric acid is a weak acid but hydrochloric acid is a strong acid.

(i) What is meant by the term *weak acid*?

..... **[2]**

(ii) Use the data in **Table 2.1** to suggest why hydrofluoric acid is a weaker acid than hydrochloric acid.

..... **[1]**

(iii) Write the equation for the reaction between hydrofluoric acid and solid sodium carbonate, Na_2CO_3.

..... **[1]**

(iv) Write the **ionic** equation for the reaction between hydrofluoric acid and solid sodium carbonate, Na_2CO_3.

..... **[1]**

(v) Describe how the reaction with Na_2CO_3 can be used to show that hydrochloric acid is strong and hydrofluoric acid is weak.

..... **[2]**

[Total: 15]

3 Hydrogen is needed in large quantities for the manufacture of ammonia and margarine. Methane and steam can be used to manufacture hydrogen. This is a reversible reaction.

$$CH_4(g) + H_2O(g) \rightleftharpoons CO(g) + 3H_2(g) \qquad \Delta H = +210\,kJ\,mol^{-1}$$ **equation 3.1**

(a) Describe the conditions that would produce a high yield of hydrogen at equilibrium. Explain your answers.

temperature .....

.....

.....

pressure .....

.....

..... **[4]**

(b) Describe the conditions that would produce hydrogen at a fast rate. Explain your answers.

temperature .....

.....

.....

pressure .....

.....

..... **[4]**

(c) Use your answers to **(a)** and **(b)** to suggest why a temperature of 800 °C and a pressure of 30 atm might be used for the manufacture of hydrogen from methane and steam.

.....

.....

.....

.....

..... **[3]**

(d) The carbon monoxide produced in the reaction can be used as a fuel.

Hess's Law can be used to calculate the enthalpy change of formation, ΔH_f, of carbon monoxide.

(i) State *Hess's Law*.

.....

.....

..... **[1]**

(ii) The table below shows some enthalpy changes of formation, ΔH_f.

substance	ΔH_f / kJ mol^{-1}
$CH_4(g)$	–75
$H_2O(g)$	–242

Use these data, and the enthalpy change of **equation 3.1**, to determine the enthalpy change of formation of carbon monoxide.

ΔH_f = ... kJ mol^{-1} **[3]**

[Total: 15]

4 Catalysts are often used to speed up chemical reactions.

(a) Explain how a catalyst increases the rate of a reaction.

Use an enthalpy profile diagram and a Boltzmann distribution in your answer.

Enthalpy profile diagram

Boltzmann distribution

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.....

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.....

.....

..... [8]

(b) Explain the effect that adding a catalyst has on the position of equilibrium in a reversible reaction.

.....

.....

..... [2]

[Total: 10]

END OF QUESTION PAPER

Answer **all** the questions.

1 Glucose, $C_6H_{12}O_6$, can be used directly as a source of energy in living species or fermented to produce ethanol, C_2H_5OH. The ethanol produced can then be used as a fuel.

(a) Energy is released from the oxidation of glucose in living species.

(i) What name is given to this process?

..... [1]

(ii) Write the equation for this oxidation.

..... [1]

(b) When ethanol is used as a fuel, a combustion reaction takes place. The equation for this process is shown below.

$$C_2H_5OH(l) + 3O_2(g) \longrightarrow 2CO_2(g) + 3H_2O(l) \qquad \Delta H^{\ominus} = -1367 \text{ kJ mol}^{-1}$$

Table 1.1 shows values for standard enthalpy changes of formation, $\Delta H_f^{\ominus}$.

compound	$\Delta H_f^{\ominus}$ / kJ mol^{-1}
$CO_2(g)$	–394
$H_2O(l)$	–286

Table 1.1

(i) Define the term *standard enthalpy change of formation.*

.....

.....

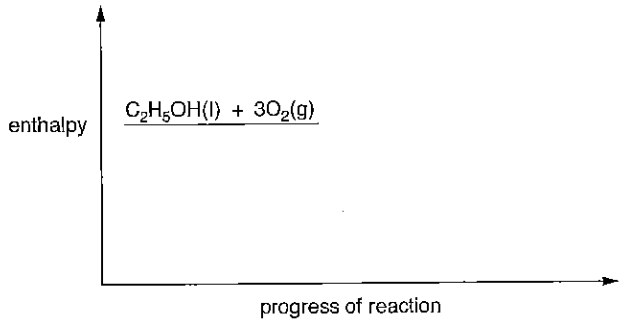
.....

..... [3]

(ii) Calculate the standard enthalpy change of formation of ethanol.

$\Delta H_f^{\ominus}$ = ... kJ mol^{-1} **[3]**

(iii) On the axes below draw the enthalpy profile diagram for the combustion of ethanol. Label E_a and $\Delta H^{\ominus}$ on your diagram.



[3]

(c) Ethanol can be made industrially by reacting ethene with steam using a catalyst.

$$C_2H_4(g) + H_2O(g) \rightleftharpoons C_2H_5OH(g)$$

At equilibrium the percentage conversion of ethene using excess steam, at various reaction conditions, is shown below.

pressure/atm	temperature/°C	percentage conversion (%)
50	200	45
50	320	30
80	200	60
80	320	45

(i) State and explain the effect of increasing the pressure on the percentage conversion.

.....

.....

.....

..... **[2]**

(ii) Use the data to deduce the sign of the enthalpy change for the forward reaction. Explain how you reached your conclusion.

.....

.....

.....

..... **[2]**

(iii) The equation for the formation of ethanol shows that equal numbers of moles of ethene and steam are required. In industry however excess steam is used.

Suggest why excess steam is used.

.....

..... **[1]**

[Total: 16]

3 This question is concerned with some halogenoalkanes that were, in the past, widely used industrially and in the home.

(a) Tetrachloromethane, CCl_4, was used as a dry cleaning solvent and in fire extinguishers.

CCl_4 was made by the reaction between chlorine and carbon disulphide, CS_2, as shown below.

$$S{=}C{=}S(g) + 3Cl{-}Cl(g) \rightarrow Cl{-}\underset{\displaystyle Cl}{\overset{\displaystyle Cl}{\underset{|}{\overset{|}{C}}}}{-}Cl(g) + Cl{-}S{-}S{-}Cl(g) \qquad \Delta H = -272\,kJ\,mol^{-1}$$

Some bond enthalpies are given in **Table 3.1**.

bond	bond enthalpy/kJ mol^{-1}
C–Cl	+328
C–F	+485
C=S	+543
S–Cl	+253
S–S	+266

Table 3.1

Calculate the bond enthalpy for the Cl–Cl bond.

[3]

(b) Trichlorofluoromethane, $CFCl_3$, was used as a coolant and is still used in some inhalers. Its boiling point is 24 °C at 1 atm pressure.

Write the equation, including state symbols, for the enthalpy change of formation of $CFCl_3$ at 25 °C and 1 atm pressure.

.....**[2]**

(c) It is now known that $CFCl_3$ breaks down the ozone layer. For this reason, $CFCl_3$ is no longer manufactured in large quantities.

The first stage in ozone breakdown is the formation of a halogen free radical. This free radical catalyses the breakdown of ozone.

(i) Use the data in **Table 3.1** to suggest which free radical is formed from $CFCl_3$. Give a reason for your answer.

.....

.....

.....**[1]**

(ii) What type of catalysis is shown by the halogen free radical in the breakdown of ozone? Give a reason for your answer.

type of catalysis .....

reason .....

.....**[2]**

[Total: 8]

4 The rate of many gaseous reactions is approximately doubled by a temperature increase of 10 °C. The number of collisions is only increased a small amount by this temperature rise.

Use a Boltzmann distribution to explain why an increase in temperature has such a significant effect on the rate of a reaction.

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..... [4]

[Total: 4]

5 Nitric acid, HNO_3, is a strong acid which can react in a similar way to hydrochloric acid.

(a) Explain, with the aid of an equation, the meaning of the term *strong* applied to nitric acid.

.....

..... [2]

(b) (i) Write the equation for the reaction that occurs when solid magnesium carbonate, $MgCO_3$, is added to aqueous nitric acid.

..... [1]

(ii) What is **observed** when solid magnesium carbonate is added to aqueous nitric acid?

.....

..... [1]

(iii) Write the ionic equation for the reaction between solid magnesium carbonate and aqueous nitric acid.

..... [1]

(c) Nitric acid reacts with ammonia, NH_3, to form ammonium nitrate, NH_4NO_3.

$$NH_3(g) + HNO_3(aq) \longrightarrow NH_4NO_3(aq)$$

NH_4NO_3 can be used as a fertiliser because it contains a high percentage of nitrogen.

(i) Why does ammonia react with nitric acid?

..... [1]

(ii) Calculate the percentage, by mass, of nitrogen in NH_4NO_3.

[2]

[Total: 8]

END OF QUESTION PAPER