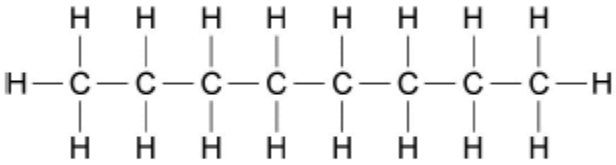
1 Octane and isooctane are structural isomers with the molecular formula C_8H_{18}.
The displayed formulas and boiling points of octane and isooctane are shown in **Figure 1**.

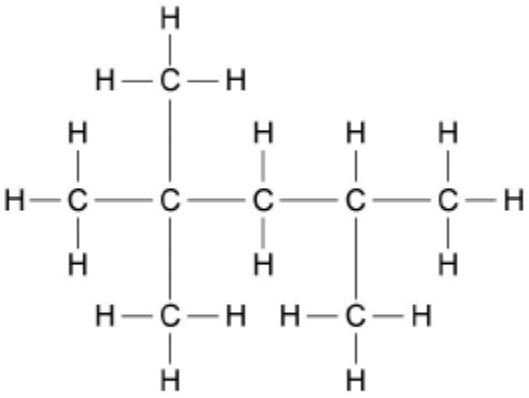
Figure 1

Octane



Boiling point: 125 °C

Isooctane



Boiling point: 99 °C

(a) Give the IUPAC name for isooctane.

.....

(1)

(b) Octane and isooctane can be separated in the laboratory.

Name a laboratory technique that could be used to separate isooctane from a mixture of octane and isooctane.

Outline how this technique separates isooctane from octane.

Name .....

Outline .....

.....

.....

.....

.....

(3)

(c) Isooctane is added to petrol to increase its octane rating. Some high-performance engines require fuel with a higher octane rating.

Write an equation for the complete combustion of isooctane. Use the molecular formula (C_8H_{18}) of isooctane in your equation.

.....

(1)

(d) Explain, in general terms, how a catalyst works.

.....

.....

.....

(2)

(e) Carbon monoxide is produced when incomplete combustion takes place in engines. Nitrogen monoxide is another pollutant produced in car engines.

Write an equation to show how these pollutants react together in a catalytic converter.

.....

(1)

(f) Platinum, palladium and rhodium are metals used inside catalytic converters. A very thin layer of the metals is used on a honeycomb ceramic support.

Explain why a thin layer is used in this way.

.....

.....

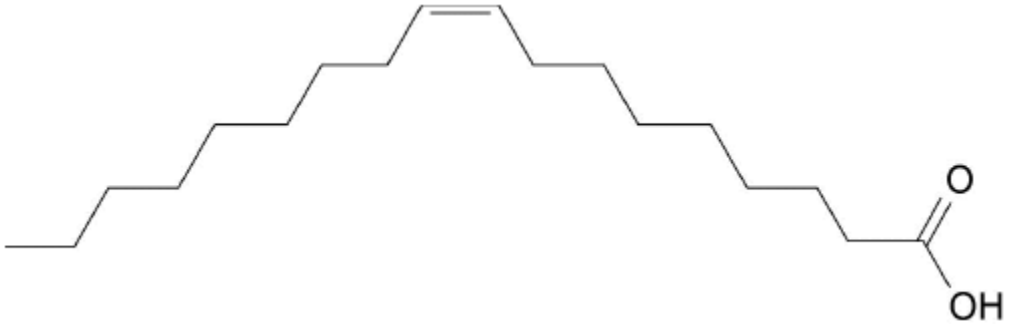
.....

.....

(2)

(g) Oleic acid ($C_{18}H_{34}O_2$) is a straight-chain fatty acid obtained from plant oils. Isooctane can be made from oleic acid. The skeletal formula of oleic acid is shown in **Figure 2**.

Figure 2



Identify a reagent that could be used in a chemical test to show that oleic acid is unsaturated.

State what would be observed in this test.

Reagent .....

Observation.....

.....

(2)

(Total 12 marks)

2 Refrigerants are substances used to cool refrigerators and freezers. Until recently, many of the compounds used as refrigerants were chlorofluorocarbons (CFCs), but these are now known to form chlorine radicals. CFCs have been phased out in many countries by international agreement.

(a) Write **two** equations to show how chlorine radicals react with ozone molecules in the upper atmosphere.

1 .....

2 .....

(2)

(b) Chloropentafluoroethane is a CFC that has been used as a refrigerant.

Draw its displayed formula.

(1)

(c) 1,1,1-trifluoroethane (CF_3CH_3) is one of the molecules that has been used as a refrigerant in place of CFCs.

Explain why 1,1,1-trifluoroethane does not lead to the depletion of the ozone in the upper atmosphere.

.....

.....

.....

(1)

(d) One of the steps in the synthesis of 1,1,1-trifluoroethane (CF_3CH_3) is the reaction of 1,1-difluoroethane (CHF_2CH_3) with fluorine in a free-radical substitution reaction.

Write **two** equations to represent the propagation steps in this conversion of CHF_2CH_3 into CF_3CH_3

Propagation step 1

.....

Propagation step 2

.....

(2)

(e) A refrigerator contains 1.41 kg of 1,1,1-trifluoroethane (CF_3CH_3).

Calculate the number of molecules of 1,1,1-trifluoroethane in the refrigerator.
Give your answer to an appropriate number of significant figures.
(The Avogadro constant L = 6.022×10^{23} mol^{-1})

.....

.....

.....

(2)

(f) There are growing concerns about the use of 1,1,1-trifluoroethane as a refrigerant as it is a greenhouse gas that absorbs some of Earth's infrared radiation.

Give **one** reason why bonds in molecules such as carbon dioxide and 1,1,1-trifluoroethane absorb infrared radiation.

.....

.....

(1)
(Total 9 marks)

3 Sulfur dioxide (SO_2) is produced when some fossil fuels are burned.

Which of the following statements is true?

A Sulfur dioxide can be removed from waste gases in a power station by an acid-base reaction with calcium oxide. ⬭

B Sulfur dioxide is insoluble in water. ⬭

C Sulfur dioxide is a basic oxide. ⬭

D Sulfur dioxide is an ionic compound. ⬭

(Total 1 mark)

4 Tetradecane ($C_{14}H_{30}$) is an alkane found in crude oil. When tetradecane is heated to a high temperature, one molecule of tetradecane decomposes to form one molecule of hexane and three more molecules.

Which of the following could represent this reaction?

A $C_{14}H_{30} \rightarrow C_6H_{14} + C_4H_8 + 2C_2H_4$ ⬭

B $C_{14}H_{30} \rightarrow C_6H_{14} + C_6H_{12} + C_2H_4$ ⬭

C $C_{14}H_{30} \rightarrow C_5H_{12} + 3C_3H_6$ ⬭

D $C_{14}H_{30} \rightarrow C_6H_{14} + C_2H_6 + 2C_3H_6$ ⬭

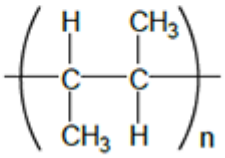
(Total 1 mark)

5 Dodecane ($C_{12}H_{26}$) is a hydrocarbon found in the naphtha fraction of crude oil. Dodecane can be used as a starting material to produce a wide variety of useful products. The scheme below shows how one such product, polymer **Y**, can be produced from dodecane.

Reaction **1**

$C_{12}H_{26} \longrightarrow C_2H_4 + C_4H_8 + \mathbf{X}$

Reaction **2**

$nC_4H_8 \rightleftharpoons$ 

Polymer **Y**

(a) Name the homologous series that both C_2H_4 and C_4H_8 belong to.
Draw a functional group isomer of C_4H_8 that does **not** belong to this homologous series.

Name .....

Functional group isomer

(2)

(b) Identify compound **X**.

.....

(1)

(c) Name polymer **Y**.

.....

(1)

(d) Reaction **1** is an example of thermal cracking and is carried out at a temperature of 750 °C.

State **one other** reaction condition needed.

.....

(1)

(e) Reaction **2** is exothermic. A typical compromise temperature of 200 °C is used industrially for this reaction.

Explain the effect of a change of temperature on both the position of equilibrium and the rate of reaction, and justify why a compromise temperature is used industrially.

.....

.....

.....

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.....

.....

.....

.....

.....

(6)
(Total 11 marks)

6 Which of these substances does **not** contribute to the greenhouse effect?

A Unburned hydrocarbons. ⬭

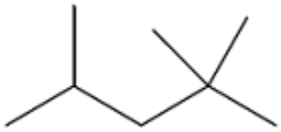
B Carbon dioxide. ⬭

C Water vapour. ⬭

D Nitrogen. ⬭

(Total 1 mark)

7 Isooctane (C_8H_{18}) is the common name for the branched-chain hydrocarbon that burns smoothly in car engines. The skeletal formula of isooctane is shown below.



(a) Give the IUPAC name for isooctane.

.....

(1)

(b) Deduce the number of peaks in the ^{13}C NMR spectrum of isooctane.

5 ⬭

6 ⬭

7 ⬭

8 ⬭

(1)

(c) Isooctane can be formed, together with propene and ethene, in a reaction in which one molecule of an alkane that contains 20 carbon atoms is cracked.

Using molecular formulas, write an equation for this reaction.

.....

(1)

(d) How do the products of the reaction in part (c) show that the reaction is an example of thermal cracking?

.....

(1)

(e) Deduce the number of monochloro isomers formed by isooctane.
Draw the structure of the monochloro isomer that exists as a pair of optical isomers.

Number of monochloro isomers .....

Structure

(2)

(f) An isomer of isooctane reacts with chlorine to form only one monochloro compound.

Draw the **skeletal formula** of this monochloro compound.

(1)

(g) A sample of a monochlorooctane is obtained from a comet. The chlorine in the monochlorooctane contains the isotopes ^{35}Cl and ^{37}Cl in the ratio 1.5 : 1.0
Calculate the M_r of this monochlorooctane.

M_r = ...

(2)

(h) Isooctane reacts with an excess of chlorine to form a mixture of chlorinated compounds. One of these compounds contains 24.6% carbon and 2.56% hydrogen by mass. Calculate the molecular formula of this compound.

Molecular formula = ...

(3)

(Total 12 marks)

8 Which molecule is **not** produced when ethane reacts with bromine in the presence of ultraviolet light?

A $C_2H_4Br_2$ ⬭

B HBr ⬭

C H_2 ⬭

D C_4H_{10} ⬭

(Total 1 mark)

9 Central heating fuel, obtained by the fractional distillation of crude oil, contains saturated hydrocarbons with the molecular formula $C_{16}H_{34}$

(a) Give the meaning of the terms **saturated** and **hydrocarbon** as applied to saturated hydrocarbons.

Saturated .....

.....

Hydrocarbon .....

.....

(2)

(b) If the boiler for a central heating system is faulty, a poisonous gas may be produced during the combustion of $C_{16}H_{34}$

Write an equation for the reaction that forms this poisonous gas and one other product only.

.....

(1)

(c) Explain why the sulfur compounds found in crude oil should be removed from the fractions before they are used for central heating fuel.

.....

.....

.....

.....

.....

(2)

(d) A hydrocarbon $C_{16}H_{34}$ can be cracked to form C_8H_{18}, ethene and propene.

(i) Write an equation to show this cracking reaction.

.....

(1)

(ii) Suggest **one** important substance manufactured on a large scale from propene.

.....

(1)

(iii) Draw the **displayed formula** of the functional group isomer of propene.

(1)

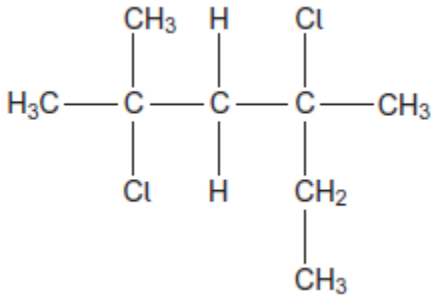
(e) There are many structural isomers with the molecular formula C_8H_{18}

Draw the structure of 2,3,3-trimethylpentane.

(1)

(f) A compound C_8H_{18} reacts with chlorine to give several haloalkanes.

Give the IUPAC name of the following haloalkane.



.....

(1)
(Total 10 marks)

10 There are many uses of halogenated organic compounds despite environmental concerns.

(a) Bromotrifluoromethane is used in fire extinguishers in aircraft.
Bromotrifluoromethane is formed when trifluoromethane reacts with bromine.

$$CHF_3 + Br_2 \longrightarrow CBrF_3 + HBr$$

The reaction is a free-radical substitution reaction similar to the reaction of methane with chlorine.

(i) Write an equation for each of the following steps in the mechanism for the reaction of CHF_3 with Br_2

Initiation step

.....

First propagation step

.....

Second propagation step

.....

A termination step

.....

(4)

(ii) State **one** condition necessary for the initiation of this reaction.

.....

(1)

(b) Bromine-containing and chlorine-containing organic compounds may have a role in the decomposition of ozone in the upper atmosphere.

(i) Draw an appropriate **displayed formula** in the space provided to complete the following equation to show how $CBrF_3$ may produce bromine atoms in the upper atmosphere.

$$CBrF_3 \longrightarrow \quad\quad + \quad Br^{\bullet}$$

.....

(1)

(ii) In the upper atmosphere, it is more likely for $CBrF_3$ to produce bromine atoms than it is for $CClF_3$ to produce chlorine atoms.

Suggest **one** reason for this.

.....

.....

.....

(1)

(iii) Bromine atoms have a similar role to chlorine atoms in the decomposition of ozone.
The overall equation for the decomposition of ozone is

$$2O_3 \longrightarrow 3O_2$$

Write **two** equations to show how bromine atoms (Br•) act as a catalyst in the decomposition of ozone.

Explain how these two decomposition equations show that bromine atoms behave as a catalyst.

Equation 1

.....

Equation 2

.....

Explanation .....

.....

.....

(3)
(Total 10 marks)

11 Some oil-fired heaters use paraffin as a fuel.
One of the compounds in paraffin is the straight-chain alkane, dodecane ($C_{12}H_{26}$).

(a) Give the name of the substance from which paraffin is obtained.
State the name of the process used to obtain paraffin from this substance.

Substance .....

Process .....

(2)

(b) The combustion of dodecane produces several products.

Write an equation for the **incomplete** combustion of dodecane to produce gaseous products only.

.....

(1)

(c) Oxides of nitrogen are also produced during the combustion of paraffin in air.

(i) Explain how these oxides of nitrogen are formed.

.....

.....

.....

.....

(2)

(ii) Write an equation to show how nitrogen monoxide in the air is converted into nitrogen dioxide.

.....

(1)

(iii) Nitric acid (HNO_3) contributes to acidity in rainwater.

Deduce an equation to show how nitrogen dioxide reacts with oxygen and water to form nitric acid.

.....

(1)

(d) Dodecane ($C_{12}H_{26}$) can be cracked to form other compounds.

(i) Give the general formula for the homologous series that contains dodecane.

.....

(1)

(ii) Write an equation for the cracking of one molecule of dodecane into equal amounts of two different molecules each containing the same number of carbon atoms.
State the empirical formula of the straight-chain alkane that is formed.
Name the catalyst used in this reaction.

Equation .....

Empirical formula of alkane .....

Catalyst .....

.....

(3)

(iii) Explain why the melting point of dodecane is higher than the melting point of the straight-chain alkane produced by cracking dodecane.

.....

.....

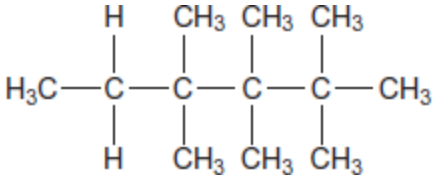
.....

.....

.....

(2)

(e) Give the IUPAC name for the following compound and state the type of structural isomerism shown by this compound and dodecane.



IUPAC name .....

Type of structural isomerism .....

(2)

(f) Dodecane can be converted into halododecanes.

Deduce the formula of a substance that could be reacted with dodecane to produce 1-chlorododecane and hydrogen chloride only.

.....

(1)

(Total 16 marks)

12 Trifluoromethane (CHF_3) can be used to make the refrigerant chlorotrifluoromethane($CClF_3$).

(a) Chlorotrifluoromethane is formed when trifluoromethane reacts with chlorine.

$$CHF_3 + Cl_2 \longrightarrow CClF_3 + HCl$$

The reaction is a free-radical substitution reaction similar to the reaction of methane with chlorine.

(i) Write an equation for each of the following steps in the mechanism for the reaction of CHF_3 with Cl_2

Initiation step

.....

First propagation step

.....

Second propagation step

.....

Termination step to form hexafluoroethane

.....

(4)

(ii) Give **one** essential condition for this reaction.

.....

(1)

(b) In some refrigeration systems, CHF_3 has replaced $CClF_3$ because of concerns about ozone depletion.

(i) Identify the species formed from $CClF_3$ that is responsible for the catalytic decomposition of ozone in the upper atmosphere.

.....

(1)

(ii) Write an overall equation to represent the decomposition of ozone into oxygen.

.....

(1)

(Total 7 marks)

13 (a) The hydrocarbon but-1-ene (C_4H_8) is a member of the homologous series of alkenes. But-1-ene has structural isomers.

(i) State the meaning of the term *structural isomers*.

.....

.....

.....

.....

(2)

(ii) Give the IUPAC name of the **position** isomer of but-1-ene.

.....

(1)

(iii) Give the IUPAC name of the **chain** isomer of but-1-ene.

.....

(1)

(iv) Draw the displayed formula of a **functional group** isomer of but-1-ene.

(1)

(b) But-1-ene burns in a limited supply of air to produce a solid and water only.

(i) Write an equation for this reaction.

.....

(1)

(ii) State **one** hazard associated with the solid product in part (b)(i).

.....

(1)

(c) One mole of compound **Y** is cracked to produce two moles of ethene, one mole of but-1-ene and one mole of octane (C_8H_{18}) only.

(i) Deduce the molecular formula of **Y**.

.....

(1)

(ii) Other than cracking, give **one** common use of **Y**.

.....

(1)

(d) In cars fitted with catalytic converters, unburned octane reacts with nitrogen monoxide to form carbon dioxide, water and nitrogen only.

(i) Write an equation for this reaction.

.....

(1)

(ii) Identify a catalyst used in a catalytic converter.

.....

(1)

(Total 11 marks)

14 Chlorine can be used to make chlorinated alkanes such as dichloromethane.

(a) Write an equation for each of the following steps in the mechanism for the reaction of chloromethane (CH_3Cl) with chlorine to form dichloromethane (CH_2Cl_2).

Initiation step

.....

First propagation step

.....

Second propagation step

.....

The termination step that forms a compound with empirical formula CH_2Cl.

.....

(4)

(b) When chlorinated alkanes enter the upper atmosphere, carbon-chlorine bonds are broken. This process produces a reactive intermediate that catalyses the decomposition of ozone. The overall equation for this decomposition is

$$2O_3 \rightleftharpoons 3O_2$$

(i) Name the type of reactive intermediate that acts as a catalyst in this reaction.

.....

(1)

(ii) Write **two** equations to show how this intermediate is involved as a catalyst in them decomposition of ozone.

Equation 1.....

Equation 2.....

(2)
(Total 7 marks)

15 The following table shows the boiling points of some straight-chain alkanes.

	CH_4	C_2H_6	C_3H_8	C_4H_{10}	C_5H_{12}
Boiling point / °C	−162	−88	−42	−1	36

(a) State a process used to separate an alkane from a mixture of these alkanes.

.....

(1)

(b) Both C_3H_8 and C_4H_{10} can be liquefied and used as fuels for camping stoves.

Suggest, with a reason, which of these two fuels is liquefied more easily.

.....

.....

.....

(1)

(c) Write an equation for the complete combustion of C_4H_{10}

.....

(1)

(d) Explain why the complete combustion of C_4H_{10} may contribute to environmental problems.

.....

.....

.....

(1)

(e) Balance the following equation that shows how butane is used to make the compound called maleic anhydride.

..... $CH_3CH_2CH_2CH_3$ + ... O_2 ⟶ ..... $C_2H_2(CO)_2O$ + ... H_2O

(1)

(f) Ethanethiol (C_2H_5SH), a compound with an unpleasant smell, is added to gas to enable leaks from gas pipes to be more easily detected.

(i) Write an equation for the combustion of ethanethiol to form carbon dioxide, water and sulfur dioxide.

.....

(1)

(ii) Identify a compound that is used to react with the sulfur dioxide in the products of combustion before they enter the atmosphere.

Give **one** reason why this compound reacts with sulfur dioxide.

Substance .....

Reason .....

.....

(2)

(iii) Ethanethiol and ethanol molecules have similar shapes.

Explain why ethanol has the higher boiling point.

.....

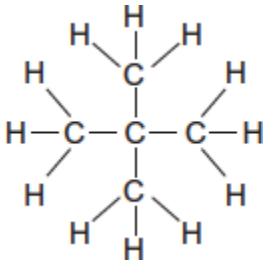
.....

.....

.....

(2)

(g) The following compound **X** is an isomer of one of the alkanes in the table on above.



(i) Give the IUPAC name of **X**.

.....

(1)

(ii) **X** has a boiling point of 9.5 °C.

Explain why the boiling point of **X** is lower than that of its straight-chain isomer.

.....

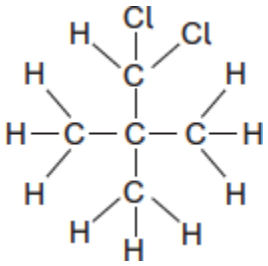
.....

.....

.....

(2)

(iii) The following compound **Y** is produced when **X** reacts with chlorine.



Deduce how many **other** position isomers of **Y** can be formed.
Write the number of **other** position isomers in this box.

(1)

(h) Cracking of one molecule of an alkane **Z** produces one molecule of ethane, one molecule of propene and two molecules of ethene.

(i) Deduce the molecular formula of **Z**.

.....

(1)

(ii) State the type of cracking that produces a high proportion of ethene and propene.
Give the **two** conditions for this cracking process.

Type of cracking .....

Conditions .....

.....

(2)
(Total 17 marks)

16 The refrigerant R410A, used in air conditioners, is a mixture of two fluoroalkanes, pentafluoroethane and difluoromethane.

(a) (i) The mechanism for the reaction of fluorine with either an alkane or a fluoroalkane is similar to that for the reaction of chlorine with methane.

Name the type of mechanism for the reaction of chlorine with methane.

.....

(1)

(ii) Write equations for the following steps in the mechanism for the reaction of fluorine with fluoromethane (CH_3F) to form difluoromethane (CH_2F_2).

Initiation step

.....

First propagation step

.....

Second propagation step

.....

A termination step leading to the formation of 1,2-difluoroethane.

.....

(4)

(iii) Write an overall equation for the reaction of fluorine with ethane to form pentafluoroethane (CF_3CHF_2) by this mechanism.

.....

(1)

(b) The refrigerant R112A (CCl_3CF_2Cl) has been banned because of concerns about ozone depletion.

Give the IUPAC name for CCl_3CF_2Cl

.....

(1)

(c) Nitrogen monoxide (NO) catalyses the decomposition of ozone into oxygen.

(i) Write the overall equation for this decomposition.

.....

(1)

(ii) Use the overall equation to deduce Step **3** in the following mechanism that shows how nitrogen monoxide catalyses this decomposition.

Step **1** $O_3 \longrightarrow O + O_2$

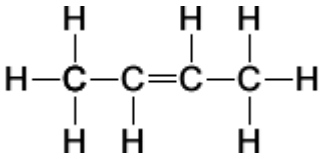
Step **2** $NO + O_3 \longrightarrow NO_2 + O_2$

Step **3** .....

(1)

(Total 9 marks)

17 Compound **X** is shown below. It is a member of a homologous series of hydrocarbons.



(a) (i) Deduce the general formula of the homologous series that contains **X**.

.....

(1)

(ii) Name a process used to obtain a sample of **X** from a mixture containing other members of the same homologous series.

.....

(1)

(b) There are several isomers of **X**.

(i) Give the IUPAC name of the position isomer of **X**.

.....

(1)

(ii) Draw the structure of a functional group isomer of **X**.

(1)

(c) At high temperatures, one molecule of $C_{15}H_{32}$ can be converted into two molecules of **X** and one molecule of another compound.

(i) Write an equation for this reaction.

.....

(1)

(ii) State the name of the process used to obtain a high yield of **X** from $C_{15}H_{32}$
Give **one** reason why this process is used in industry.

Name .....

Reason .....

.....

(2)

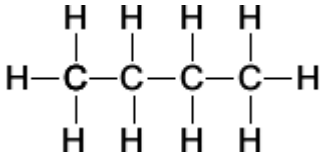
(iii) State why high temperatures are needed for this process.

.....

.....

(1)

(d) Compound **X** can be converted into compound **Y**.
Compound **Y** is shown below.



(i) Suggest the formula of a reagent that could be added to **X** in order to convert it into **Y**.

.....

(1)

(ii) Give **one** use of **Y**.

.....

(1)

(iii) Write an equation to show the reaction of **Y** in a limited supply of air to produce a solid and water only.

.....

(1)

(iv) When a sample of **Y**, contaminated with CH_3SH, is burned completely in air, a toxic gas is formed.
Identify this toxic gas and suggest a compound that could be used to remove the toxic gas from the products of combustion.

Toxic gas .....

Compound used to remove toxic gas .....

.....

(2)

(v) Suggest the name of the process that occurs when the toxic gas in part (d)(iv) is removed.

.....

(1)

(e) Explain why the boiling points of **X** and **Y** are similar.

.....

.....

.....

.....

(2)
(Total 16 marks)

18 Methanol (CH_3OH) is an important fuel that can be synthesised from carbon dioxide.

(a) The table shows some standard enthalpies of formation.

	$CO_2(g)$	$H_2(g)$	$CH_3OH(g)$	$H_2O(g)$
$\Delta H_f^{\ominus}$/kJ mol^{-1}	– 394	0	– 201	– 242

(i) Use these standard enthalpies of formation to calculate a value for the standard enthalpy change of this synthesis.

$$CO_2(g) + 3H_2(g) \rightleftharpoons CH_3OH(g) + H_2O(g)$$

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(Extra space) .....

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(3)

(ii) State why the standard enthalpy of formation for hydrogen gas is zero.

.....

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(1)

(b) State and explain what happens to the yield of methanol when the total pressure is increased in this synthesis.

$$CO_2(g) + 3H_2(g) \rightleftharpoons CH_3OH(g) + H_2O(g)$$

Effect on yield .....

Explanation .....

.....

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(Extra space) .....

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(3)

(c) The hydrogen required for this synthesis is formed from methane and steam in a reversible reaction. The equation for this reaction is shown below.

$$CH_4(g) + H_2O(g) \rightleftharpoons C0(g) + 3H_2(g) \qquad \Delta H = +206 \text{ kJ mol}^{-1}$$

State and explain what happens to the yield of hydrogen in this reaction when the temperature is increased.

Effect on yield .....

Explanation .....

.....

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(Extra space) .....

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(3)

(d) The methanol produced by this synthesis has been described as a carbon-neutral fuel.

(i) State the meaning of the term *carbon-neutral*.

.....

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(Extra space) .....

.....

(1)

(ii) Write an equation for the complete combustion of methanol.

.....

(1)

(iii) The equation for the synthesis of methanol is shown below.

$$CO_2(g) + 3H_2(g) \rightleftharpoons CH_3OH(g) + H_2O(g)$$

Use this equation and your answer to part (d)(ii) to deduce an equation to represent the overall chemical change that occurs when methanol behaves as a carbon-neutral fuel.

Equation .....

(1)

(e) A student carried out an experiment to determine the enthalpy change when a sample of methanol was burned.

The student found that the temperature of 140 g of water increased by 7.5 °C when 0.011 mol of methanol was burned in air and the heat produced was used to warm the water.

Use the student's results to calculate a value, in kJ mol $^{-1}$, for the enthalpy change when one mole of methanol was burned.

(The specific heat capacity of water is 4.18 J K^{-1} g^{-1}).

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(Extra space) .....

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(3)

(Total 16 marks)

19 Chloromethanes, such as dichloromethane and trichloromethane, are produced in industry as they have many uses.
Trichloromethane has been used in the manufacture of the refrigerant chlorodifluoromethane.

(a) Chlorine can react with dichloromethane (CH_2Cl_2) to form trichloromethane ($CHCl_3$).

(i) Write an equation for each of the following steps in the mechanism for this reaction.

Initiation step

.....

First propagation step

.....

Second propagation step

.....

(3)

(ii) Give **one** essential condition for this reaction and name the type of mechanism.

Essential condition .....

Type of mechanism .....

(2)

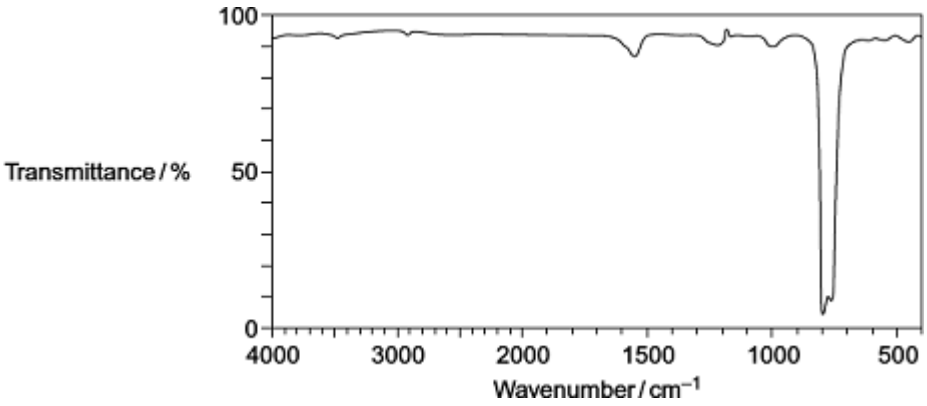
(b) An organic product, **X**, with M_r = 154.0 is obtained when chlorine reacts with trichloromethane.

(i) Write an equation for the overall reaction of chlorine with trichloromethane to form **X**, by the same mechanism as that outlined in part (a)(i).

.....

(1)

(ii) The following infrared spectrum was obtained for a sample of **X** produced in this reaction.



Use this infrared spectrum to explain why it is possible to deduce that this sample of **X** contains no trichloromethane.
You may find it helpful to refer to **Table 1** on the Data Sheet.

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(Extra space) .....

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(2)

(c) Explain, with the aid of equations and the intermediates that form in the ozone layer, why the European Union has banned the use of chlorodifluoromethane ($CHClF_2$) as a refrigerant.

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(Extra space) .....

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(4)

(d) The compound 2,3,3,3-tetrafluoropropene is the refrigerant used in all new car air conditioners.

(i) Draw the displayed formula for 2,3,3,3-tetrafluoropropene.

(1)

(ii) Give **one** reason why 2,3,3,3-tetrafluoropropene is a more **environmentally** acceptable refrigerant than chlorodifluoromethane.

.....

.....

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(1)

(Total 14 marks)

20 Hexane (C_6H_{14}) is a member of the homologous series of alkanes.

(a) (i) Name the raw material from which hexane is obtained.

.....

(1)

(ii) Name the process used to obtain hexane from this raw material.

.....

(1)

(b) C_6H_{14} has structural isomers.

(i) Deduce the number of structural isomers with molecular formula C_6H_{14}

Write the number in this box. ☐

(Space for working)

(1)

(ii) State **one** type of structural isomerism shown by the isomers of C_6H_{14}

.....

(1)

(c) One molecule of an alkane **X** can be cracked to form one molecule of hexane and two molecules of propene.

(i) Deduce the molecular formula of **X**.

.....

.....

(1)

(ii) State the type of cracking that produces a high percentage of alkenes. State the conditions needed for this type of cracking.

Type of cracking .....

Conditions .....

.....

(2)

(iii) Explain the main economic reason why alkanes are cracked.

.....

.....

(1)

(d) Hexane can react with chlorine under certain conditions as shown in the following equation.

$$C_6H_{14} + Cl_2 \longrightarrow C_6H_{13}Cl + HCl$$

(i) Both the products are hazardous. The organic product would be labelled 'flammable'. Suggest the most suitable hazard warning for the other product.

.....

(1)

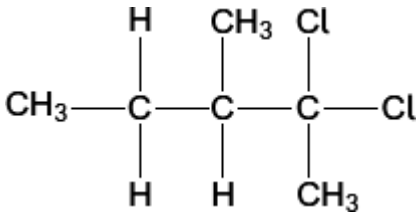
(ii) Calculate the percentage atom economy for the formation of $C_6H_{13}Cl$ (M_r = 120.5) in this reaction.

.....

.....

(1)

(e) A different chlorinated compound is shown below. Name this compound and state its empirical formula.



Name .....

Empirical formula .....

(2)

(Total 12 marks)

21 Alkanes are used as fuels. A student burned some octane (C_8H_{18}) in air and found that the combustion was incomplete.

(a) (i) Write an equation for the incomplete combustion of octane to produce carbon monoxide as the only carbon-containing product.

.....

(1)

(ii) Suggest **one** reason why the combustion was incomplete.

.....

.....

(1)

(b) Catalytic converters are used to remove the toxic gases NO and CO that are produced when alkane fuels are burned in petrol engines.

(i) Write an equation for a reaction between these two toxic gases that occurs in a catalytic converter when these gases are removed.

.....

(1)

(ii) Identify a metal used as a catalyst in a catalytic converter.
Suggest **one** reason, other than cost, why the catalyst is coated on a ceramic honeycomb.

Metal .....

Reason .....

.....

(2)

(c) If a sample of fuel for a power station is contaminated with an organic sulfur compound, a toxic gas is formed by complete combustion of this sulfur compound.

(i) State **one** environmental problem that can be caused by the release of this gas.

.....

.....

(1)

(ii) Identify **one** substance that could be used to remove this gas.
Suggest **one** reason, other than cost, why this substance is used.

Substance .....

Reason why used .....

.....

(2)
(Total 8 marks)

22 (a) There is a risk of gas explosions in coal mines. This risk is mainly due to the presence of methane. If the percentage of coal-mine methane (CMM) in the air in the mine is greater than 15%, the explosion risk is much lower. CMM slowly escapes from the mine into the atmosphere.

Write an equation to show the complete combustion of methane.

Suggest **one** reason why there is a much lower risk of an explosion if the percentage of CMM is greater than 15%.

State why it is beneficial to the environment to collect the CMM rather than allowing it to escape into the atmosphere.

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(Extra space) .....

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(3)

(b) Methane can be obtained from crude oil. Some of this crude oil contains an impurity called methanethiol (CH_3SH). This impurity causes environmental problems when burned.

Write an equation to show the complete combustion of methanethiol.

State why calcium oxide can be used to remove the sulfur-containing product of this combustion reaction.

State **one** pollution problem that is caused by the release of this sulfur-containing product into the atmosphere.

.....

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(Extra space).....

.....

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(3)
(Total 6 marks)

23 Pentane is a member of the alkane homologous series.

(a) Give the general formula for the homologous series of alkanes.

.....

(1)

(b) One of the structural isomers of pentane is 2,2-dimethylpropane.

Draw the displayed formula of 2,2-dimethylpropane.

State the type of structural isomerism shown.

.....

(2)

(c) A molecule of hydrocarbon **Y** can be thermally cracked to form one molecule of pentane and two molecules of ethene only.

Deduce the molecular formula of **Y**.

State why high temperatures are necessary for cracking reactions to occur.

Give **one** reason why thermal cracking reactions are carried out in industry.

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(Extra space) .....

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(3)

(d) Write an equation for the incomplete combustion of pentane to form a solid pollutant.

Suggest why this solid pollutant is an environmental problem.

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(Extra space) .....

.....

(2)

(e) Pentane can react with chlorine as shown in the following equation.

$$C_5H_{12} + Cl_2 \rightarrow C_5H_{11}Cl + HCl$$

Calculate the percentage atom economy for the formation of $C_5H_{11}Cl$

Deduce how many straight-chain isomers of $C_5H_{11}Cl$ could be formed.

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(Extra space).....

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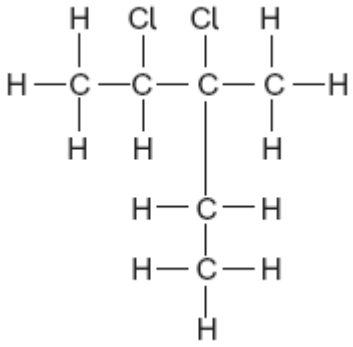
(3)

(f) Consider the following compound.



Name this compound.

Deduce the empirical formula of this compound.

.....

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.....

(2)

(Total 13 marks)

24 Halogens are used to make halogenated organic compounds.

(a) The refrigerant used in air conditioners is a mixture of fluorinated alkanes. These compounds are made by fluorination reactions.
The mechanism for the reaction of fluorine with an alkane or with a fluoroalkane is a free-radical substitution similar to the reaction of chlorine with methane.

(i) Write the overall equation for the reaction of fluorine with methane to form trifluoromethane (CHF_3).

.....

(1)

(ii) Write equations for the following steps in the mechanism for the reaction of fluorine with trifluoromethane (CHF_3) to form tetrafluoromethane (CF_4).

Initiation step

.....

First propagation step

.....

Second propagation step

.....

A termination step leading to the formation of hexafluoroethane.

.....

(4)

(b) Chlorofluorocarbons (CFCs) were used as refrigerants.
In the upper atmosphere, ultra-violet radiation breaks bonds in the CFCs to produce a reactive intermediate that catalyses the decomposition of ozone.

(i) An example of a CFC is 1,1,1-trichloro-2,2-difluoroethane.
Draw the displayed formula of this CFC.

(1)

(ii) Identify a bond in a CFC that is broken by ultra-violet radiation to produce a reactive intermediate.
Give the name of this reactive intermediate that catalyses the decomposition of ozone.
Write an overall equation for this decomposition of ozone.

Bond broken .....

Name of the reactive intermediate .....

Overall equation

.....

(3)
(Total 9 marks)

25 Cetane ($C_{16}H_{34}$) is a major component of diesel fuel.

(a) Write an equation to show the complete combustion of cetane.

.....

(1)

(b) Cetane has a melting point of 18 °C and a boiling point of 287 °C.
In polar regions vehicles that use diesel fuel may have ignition problems.
Suggest **one** possible cause of this problem with the diesel fuel.

.....

.....

(1)

(c) The pollutant gases NO and NO_2 are sometimes present in the exhaust gases of vehicles that use petrol fuel.

(i) Write an equation to show how NO is formed and give a condition needed for its formation.

Equation .....

Condition .....

(2)

(ii) Write an equation to show how NO is removed from the exhaust gases in a catalytic converter. Identify a catalyst used in the converter.

Equation .....

Catalyst .....

(2)

(iii) Deduce an equation to show how NO_2 reacts with water and oxygen to form nitric acid (HNO_3).

.....

(1)

(d) Cetane ($C_{16}H_{34}$) can be cracked to produce hexane, butene and ethene.

(i) State **one** condition that is used in this cracking reaction.

.....

(1)

(ii) Write an equation to show how one molecule of cetane can be cracked to form hexane, butene and ethene.

.....

(1)

(iii) State **one** type of useful solid material that could be formed from alkenes.

.....

(1)

(Total 10 marks)

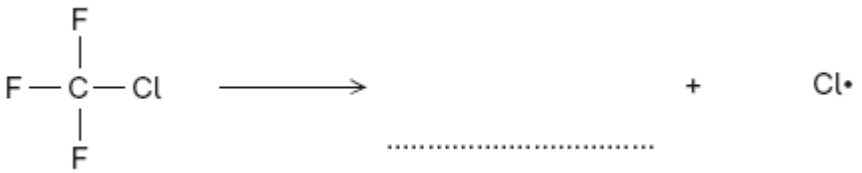
26 Oxygen and ozone (O_3) both occur as gases in the upper atmosphere.
Chlorine atoms catalyse the decomposition of ozone and contribute to the formation of a hole in the ozone layer.
These chlorine atoms are formed from chlorofluorocarbons (CFCs) such as CF_3Cl

(a) (i) Give the IUPAC name of CF_3Cl

.....

(1)

(ii) Complete the following equation that shows the formation of a chlorine atom from a molecule of CF_3Cl



(1)

(iii) State what the • represents in Cl•

.....

(1)

(b) Write two equations that show how chlorine atoms catalyse the decomposition of ozone into oxygen.

Equation 1 .....

Equation 2 .....

(2)

(c) An equilibrium is established between oxygen and ozone molecules as shown below.

$$3O_2(g) \rightleftharpoons 2O_3(g) \qquad \Delta H = +284 \text{ kJ mol}^{-1}$$

(i) State Le Chatelier's principle.

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.....

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(1)

(ii) Use Le Chatelier's principle to explain how an increase in temperature causes an increase in the equilibrium yield of ozone.

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(2)

(d) Chemists supported the legislation to ban the use of CFCs. Modern refrigerators use pentane rather than CFCs as refrigerants.
With reference to its formula, state why pentane is a more environmentally acceptable refrigerant.

.....

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(1)
(Total 9 marks)

27 (a) The reaction of bromine with propane is similar to that of chlorine with methane.
Three steps in the mechanism for the bromination of propane to form 1-bromopropane are shown below.

Step **1** $Br_2 \longrightarrow 2Br\bullet$

Step **2** $Br\bullet + CH_3CH_2CH_3 \longrightarrow CH_3CH_2CH_2\bullet + HBr$

Step **3** $CH_3CH_2CH_2\bullet + Br_2 \longrightarrow CH_3CH_2CH_2Br + Br\bullet$

(i) Name the type of mechanism in this reaction.

.....

(1)

(ii) Give an essential condition for Step **1** to occur.

.....

(1)

(iii) Name the type of step illustrated by Steps **2** and **3**.

.....

(1)

(iv) In this mechanism, a different type of step occurs in which free radicals combine.
Name this type of step.
Write an equation to show how hexane could be formed from two free radicals in the mechanism of this reaction.

Type of step .....

Equation .....

(2)

(v) Write an overall equation for the reaction between bromine and propane by the same mechanism to produce octabromopropane (C_3Br_8).

.....

(1)

(b) Bromine reacts with alkenes, even though bromine is a non-polar molecule.

(i) Explain why bromine molecules react with the double bonds in alkenes.

.....

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.....

(2)

(ii) Name the type of mechanism involved in this reaction.

.....

(1)

(iii) Draw the structure of the compound with M_r = 387.6 formed when penta-1,4-diene ($H_2C{=}CHCH_2CH{=}CH_2$) reacts with an excess of bromine.

(1)

(c) Two products are formed when propene reacts with hydrogen bromide.
Draw the structure of the intermediate that leads to the formation of the major product in the reaction of propene with hydrogen bromide.
Give the name of this type of intermediate.

Structure of intermediate

Type of intermediate .....

(2)

(Total 12 marks)

28 There are several oxides of nitrogen.

(a) An oxide of nitrogen contains 25.9% by mass of nitrogen. Determine the empirical formula of this oxide.

.....

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.....

.....

(3)

(b) Give **one** reason why the oxide NO is a pollutant gas.

.....

.....

(1)

(c) The oxide NO reacts with oxygen to form nitrogen dioxide. Write an equation for this reaction.

.....

(1)

(d) Explain how NO is produced in the engine of a motor vehicle.

.....

.....

.....

(2)

(e) Write an equation to show how NO is removed from the exhaust gases in motor vehicles using a catalytic converter.

.....

(1)
(Total 8 marks)

29 The alkane butane is used as a fuel.

(a) (i) Write an equation for the complete combustion of butane.

.....

(1)

(ii) State a condition which may cause carbon to be formed as a product in the combustion of butane.

.....

(1)

(b) Butane obtained from crude oil may contain trace amounts of an impurity.
When this impurity burns it produces a toxic gas that can be removed by reacting it with calcium oxide coated on a mesh.

(i) Suggest the identity of the toxic gas.

.....

(1)

(ii) Suggest why calcium oxide reacts with the toxic gas.

.....

(1)

(iii) Suggest why the calcium oxide is coated on a mesh.

.....

(1)
(Total 5 marks)

30 Pent-1-ene is a member of the alkene homologous series.

(a) Pent-1-ene can be separated from other alkenes.

State the physical property of alkenes that allows them to be separated from a mixture by fractional distillation.

.....

(1)

(b) (i) State the meaning of the term *structural isomerism*.

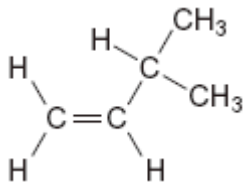
.....

.....

.....

(2)

(ii) Name the branched chain isomer of pent-1-ene shown below.



.....

(1)

(iii) Draw the structure of a functional group isomer of pent-1-ene.

(1)

(c) The cracking of one molecule of compound **X** produces pent-1-ene, ethene and butane in a 1:2:1 mol ratio.
Deduce the molecular formula of **X** and state a use for the ethene formed.

Molecular formula of **X** .....

.....

Use of ethene .....

(2)
(Total 7 marks)

31 Alkanes are saturated hydrocarbons which can be obtained from crude oil.
Pentane is an example of an alkane. A molecule of pentane contains five carbon atoms.

(a) (i) State the meaning of the term *saturated* and of the term *hydrocarbon* as applied to alkanes.

Saturated .....

.....

Hydrocarbon .....

.....

(2)

(ii) Give the general formula for the alkanes.

.....

(1)

(b) Pentane burns completely in oxygen.

(i) Write an equation for this reaction.

.....

(1)

(ii) State how the products of this reaction may affect the environment.

.....

.....

(1)

(c) Give the name of a solid pollutant which may form when pentane burns incompletely in air.

.....

(1)

(d) One molecule of C_9H_{20} can be cracked to form one molecule of pentane and one other product.

(i) Write an equation for this cracking reaction.

.....

(1)

(ii) Suggest a type of compound that can be manufactured from the other product of this cracking reaction.

.....

.....

(1)

(iii) State why a high temperature is needed for cracking reactions to occur.

.....

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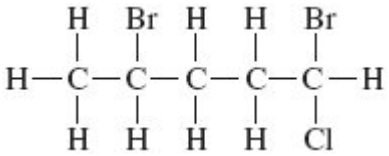
(1)

(e) Pentane can react to form the following haloalkane **Q**.

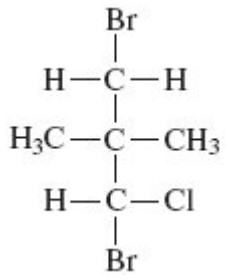


(i) Name **Q**.

.....

(1)

(ii) State the type of structural isomerism shown by **Q** and the haloalkane shown below.



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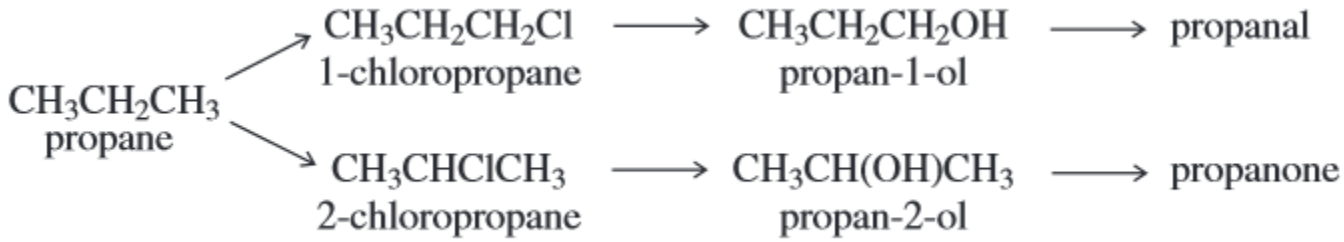
(1)

(Total 11 marks)

32 Consider the following scheme of reactions.



(a) State the type of structural isomerism shown by propanal and propanone.

.....

(1)

(b) A chemical test can be used to distinguish between separate samples of propanal and propanone.

Identify a suitable reagent for the test.
State what you would observe with propanal and with propanone.

Test reagent.....

Observation with propanal.....

Observation with propanone.....

(3)

(c) State the structural feature of propanal and propanone which can be identified from their infrared spectra by absorptions at approximately 1720 cm^{-1}.

.....

(1)

(d) The reaction of chlorine with propane is similar to the reaction of chlorine with methane.

(i) Name the type of mechanism in the reaction of chlorine with methane.

.....

(1)

(ii) Write an equation for each of the following steps in the mechanism for the reaction of chlorine with propane to form l-chloropropane ($CH_3CH_2CH_2Cl$).

Initiation step

.....

First propagation step

.....

Second propagation step

.....

A termination step to form a molecule with the empirical formula C_3H_7

.....

(4)

(e) High resolution mass spectrometry of a sample of propane indicated that it was contaminated with traces of carbon dioxide.

Use the data in the table to show how precise M_r values can be used to prove that thesample contains both of these gases.

Atom	Precise relative atomic mass
^{12}C	12.00000
^{1}H	1.00794
^{16}O	15.99491

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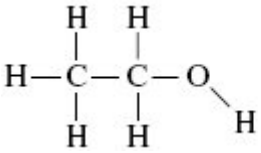
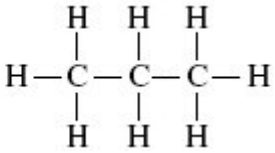
(2)
(Total 12 marks)

33 (a) Two organic compounds with similar relative molecular masses are shown below.



Ethanol



Propane

(i) State the type of bond present between the C and H atoms in both of these molecules. Explain how this type of bond is formed.

Type of bond .....

Explanation .....

(2)

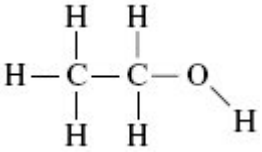
(ii) State the strongest type of intermolecular force present in each compound.

Liquid ethanol .....

Liquid propane .....

(2)

(b) Ethanol dissolves in water. Draw a diagram to show how one molecule of ethanol interacts with one molecule of water in the solution. Include partial charges and all lone pairs. The ethanol molecule has been drawn for you.



(3)

(c) Ethanol was the fuel used in the first mass-produced car, the Model T Ford.

(i) Write an equation which shows how ethanol burns completely in air to form carbon dioxide and water as the only products.

.....

(1)

(ii) Suggest **one** environmental problem caused by incomplete combustion of ethanol in a car engine.

.....

.....

(1)

(iii) Suggest **one** economic problem for the car user caused by incomplete combustion of ethanol in the car engine.

.....

.....

(1)

(d) Propane is also used as a fuel, although sometimes it can be contaminated with sulfur-containing impurities. When this propane burns, these impurities form sulfur dioxide.

(i) State how the sulfur dioxide can be removed from the waste gases produced when this propane is burned on a large scale in industry. Suggest a reason why the method you have stated may not be 100% efficient.

How removed .....

.....

Reason for less than 100% efficiency .....

.....

(2)

(ii) Although propane has a boiling point of –42 °C, it is usually supplied as a liquid for use in camping stoves. Suggest why it is supplied as a liquid.

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(1)
(Total 13 marks)

34 One of the first substances used as an anaesthetic in medicine was chloroform (trichloromethane, $CHCl_3$). By 1950, *halothane* was in common use but by 1990 this had been replaced by more acceptable anaesthetics such as *desflurane*.

$CF_3CHBrCl$	$CF_3CHFOCHF_2$
halothane	*desflurane*

One reason for replacing *halothane* was that it is an organic compound that contains chlorine. Chlorine-containing organic compounds are thought to cause damage to the ozone layer in the upper atmosphere.

(a) Name and outline a mechanism for the reaction of chlorine with methane to form chloromethane (CH_3Cl).

Write an overall equation for the reaction of chlorine with methane to form trichloromethane ($CHCl_3$).

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(5)

(b) Explain how chlorine atoms are formed from chlorine-containing organic compounds in the upper atmosphere.

Explain, with the aid of equations, how chlorine atoms act as a catalyst in the decomposition of ozone into oxygen.

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(6)

(c) Use the formulae of the two anaesthetics, *halothane* and *desflurane*, to help to explain why *desflurane* is considered to be a more **environmentally** acceptable anaesthetic than *halothane*.

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(2)
(Total 13 marks)

35 Petrol contains saturated hydrocarbons. Some of the molecules in petrol have the molecular formula C_8H_{18} and are referred to as octanes. These octanes can be obtained from crude oil by fractional distillation and by cracking suitable heavier fractions.

Petrol burns completely in a plentiful supply of air but can undergo incomplete combustion in a car engine.

(a) State the meaning of both the words *saturated* and *hydrocarbon* as applied to the term *saturated hydrocarbon*.

Name the homologous series to which C_8H_{18} belongs.

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(3)

(b) Outline the essential features of the fractional distillation of crude oil that enable the crude oil to be separated into fractions.

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(4)

(c) C_8H_{18} is obtained by the catalytic cracking of suitable heavy fractions.
State what is meant by the term *cracking* and name the catalyst used in catalytic cracking.

Write an equation to show how one molecule of $C_{14}H_{30}$ is cracked to form one molecule of C_8H_{18} and one molecule of another hydrocarbon.

Explain why oil companies need to crack 'suitable heavy fractions'.

.....

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(4)

(d) Write an equation for the incomplete combustion of C_8H_{18} to form carbon monoxide and water only.

A catalytic converter is used to remove carbon monoxide from the exhaust gases in a car.
Identify a catalyst used in the catalytic converter.

Write an equation to show how carbon monoxide is removed in a catalytic converter.

State why the water produced in the exhaust gases may contribute to global warming.

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(4)

(e) When some petrol was accidentally contaminated in 2007, the sensors in the affected cars caused a decrease in the supply of petrol to the engine.

Suggest the effect that the contaminated fuel would have on the performance of the cars.

State how the oil company might have recognised the problem before the petrol was sold.

.....

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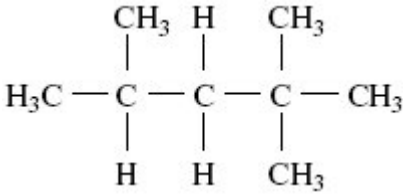
.....

(2)

(f) The molecular formula C_8H_{18} represents several structural isomers.

State what is meant by the term *structural isomers*.

Name the following structural isomer of C_8H_{18}



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(3)
(Total 20 marks)

36 (a) Hexane (C_6H_{14}) is a hydrocarbon which is a component of LPG (liquid petroleum gas), used as a fuel for heating. When burning fuels in boilers it is important to ensure complete combustion.

(i) Give two reasons why boilers are designed to ensure complete combustion.

Reason 1 .....

.....

Reason 2 .....

.....

(ii) Write an equation for the incomplete combustion of hexane.

.....

(iii) Suggest how an engineer or a chemist could demonstrate that the combustion of hexane in a faulty boiler was incomplete.

.....

(5)

(b) Branched chain alkanes are often preferred as fuels. Draw the structure of two branched chain isomers of hexane and name the first isomer.

Isomer 1 Isomer 2

Name of isomer 1 .....

(3)

(c) Hexane can be cracked in the presence of a catalyst to produce another hydrocarbon, Z, and methane.

(i) Draw a possible structure for Z.

(ii) Give a suitable catalyst for this reaction.

.....

(iii) Suggest why the product Z has more commercial value than hexane.

.....

.....

(3)

(d) The overall equation for the production of dichloromethane from methane and chlorine is shown below.

$$CH_4 + 2Cl_2 \rightarrow CH_2Cl_2 + 2HCl$$

(i) Calculate the % atom economy for the formation of CH_2Cl_2 in this reaction.

.....

.....

.....

(ii) Give one reason why this atom economy of less than 100% is an important consideration for the commercial success of this process and predict how a chemical company would maximise profits from this process.

.....

.....

.....

(3)
(Total 14 marks)

Mark schemes

1

(a) 2,2,4-trimethylpentane

This answer only but ignore punctuation

1

(b) M1 (fractional or simple) distillation

Incorrect process in M1 CE=0

If M1 blank, mark on for M2 and M3 (ignore boiling, condensing)

1

M2 idea that isooctane / the one with the lower boiling point boils (first) (or reaches top of column first)

Ignore reference to octane boiling and being collected at higher temperature

If temperature referred to, should be between 99 and 124°C

"it" refers to isooctane

M2 – allow vaporises/evaporates first

1

M3 idea that isooctane condenses / liquefies and collected

Penalise M2 and M3 if octane boils first

In M2 and M3 – if no specific reference to individual alkanes, could score one mark for M2 + M3 combined if M2 and M3 both otherwise correct

M2 and M3 must refer to a laboratory apparatus (not to an industrial process)

1

(c) $C_8H_{18} + 12½O_2 \longrightarrow 8CO_2 + 9H_2O$

Accept multiples; ignore state symbols

Accept any correct structural representation of isooctane

1

(d) M1 Alternative route/mechanism/pathway

1

M2 With lower activation energy

Accept E_a for activation energy

1

(e) $2CO + 2NO \longrightarrow 2CO_2 + N_2$

Accept multiples; ignore state symbols

1

(f) M1 to reduce amount of metals needed / small amount of metal needed

Relates to low amount of metal

1

M2 Increase / maximise / produce large surface area or to give catalyst a larger surface area: volume ratio or so that high(er) proportion of atoms/metal is on surface

Is related to large surface area

1

(g) M1 bromine (water or in organic solvent or CCl_4) / Br_2 (aq) / Br_2

No reagent or an incorrect reagent (e.g. bromide), CE=0;

Penalise Br (or incorrect formula of other correct reagent) but mark on for M2

It must be a whole reagent and/or correct formula

If oxidation state given in name, it must be correct

If 'manganate' or 'manganate(IV)' or incorrect formula, penalise M1 but mark on

Ignore 'acidified'

1

M2 (orange/yellow to) colourless / decolourised / loses its colour

Ignore goes clear

Ignore brown/red, but penalise other incorrect colours

1

Alternatives:

M1 = potassium manganate(VII), M2 = colourless

M1 = <u>conc</u> sulfuric acid, M2 = brown

M1 = iodine, M2 = colourless

[12]

2 (a) M1 $\bullet Cl + O_3 \longrightarrow \bullet ClO + O_2$

1

M2 $\bullet ClO + O_3 \longrightarrow \bullet Cl + 2O_2$

1

M1 and M2 could be in either order

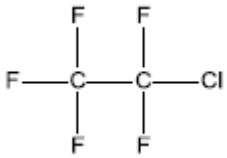
Credit the dot anywhere on the radical

Penalise absence of dot once only

Individual multiples acceptable but both need to be doubled if two marks are to be awarded

Ignore state symbols

(b)



Must be displayed formula

1

(c) Does not contain Cl or does not release Cl (atoms/radicals)
or no C-Cl bonds
or C-F bond(s) strong / does not break / no F (atom/radicals) released

1

(d) M1 $CHF_2CH_3 + \bullet F \longrightarrow \bullet CF_2CH_3 + HF$

1

M2 $\bullet CF_2CH_3 + F_2 \longrightarrow CF_3CH_3 + \bullet F$

1

M1 and M2 could be in either order

Credit the dot anywhere on the radical

Penalise absence of dot once only

(e) M1 moles CF_3CH_3 = 1410/84(.0) (=16.8, 16.79 mol)

1

M2 molecules = M1 × $6.022 \times 10^{23} = 1.01 \times 10^{25}$ (3sf only)

1

Correct answer scores both marks

Allow M2 for M1 × Avogadro with answer to 3 sf (but must have attempted to calculate moles for M1)

Ignore incorrect units

(f) (bonds) vibrate/stretch/bend OR (as bonds) are polar

NOT polar molecules; 'they' = bonds

1

[9]

3 A

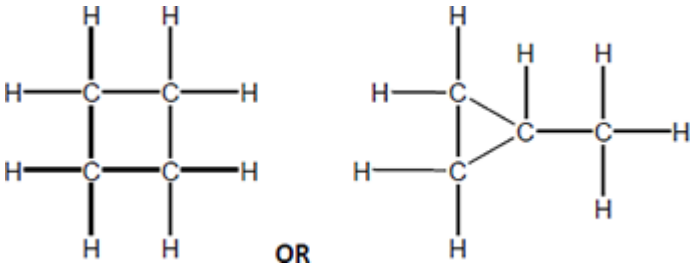
[1]

4 A

[1]

5 (a) Alkenes

1



Correctly drawn molecule of cyclobutane or methyl cyclopropane, need not be displayed formula

1

(b) C_6H_{14} (or correct alkane structure with 6 carbons)

Allow hexane or any other correctly named alkane with 6 carbons

1

(c) Poly(but-2-ene)

1

(d) High pressure

Allow pressure ≥ MPa

Mention of catalyst loses the mark

1

(e) This question is marked using levels of response. Refer to the Mark Scheme Instructions for Examiners for guidance on how to mark this question.

Level 3

All stages are covered and the explanation of each stage is generally correct and virtually complete.

Answer communicates the whole process coherently and shows a logical progression from stage 1 and stage 2 (in either order) to stage 3.

5–6 marks

Level 2

All stages are covered but the explanation of each stage may be incomplete or may contain inaccuracies OR two stages are covered and the explanations are generally correct and virtually complete.

Answer is mainly coherent and shows progression. Some steps in each stage may be out of order and incomplete.

3–4 marks

Level 1

Two stages are covered but the explanation of each stage may be incomplete or may contain inaccuracies, OR only one stage is covered but the explanation is generally correct and virtually complete.

Answer includes isolated statements but these are not presented in a logical order or show confused reasoning.

1–2 marks

Level 0

Insufficient correct chemistry to gain a mark.

0 marks

Indicative chemistry content

Stage 1*: consider effect of higher temperature on yield*

(Or vice versa for lower temperature)

- *Le Chatelier's principle predicts that equilibrium shifts to oppose any increase in temperature*
- *Exothermic reaction, so equilibrium shifts in endothermic direction / to the left*
- *So a Higher T will reduce yield*

***Stage 2**: consider effect of higher temperature on rate*

(Or vice versa for lower temperature)

- *At higher temperature, more high energy molecules*
- *more collisions have E>Ea*
- *So rate of reaction increases / time to reach equilibrium decreases*

***Stage 3**: conclusion*

Industrial conditions chosen to achieve (cost-effective) balance of suitable yield at reasonable rate

[11]

6 D

[1]

7 (a) 2,2,4-trimethylpentane

1

(b) 5

1

(c) $C_{20}H_{42} \longrightarrow C_8H_{18} + 2C_3H_6 + 3C_2H_4$

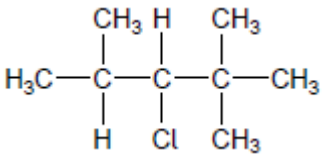
1

(d) Mainly alkenes formed

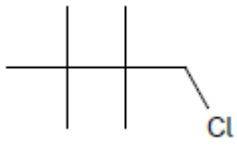
1

(e) 4 (monochloro isomers)

1



(f)



1

(g) $C_8H_{17}{}^{35}Cl = 96.0 + 17.0 + 35.0 = 148.0$
and $C_8H_{17}{}^{37}Cl = 96.0 + 17.0 + 37.0 = 150.0$

Both required

1

M_r of this $C_8H_{17}Cl$ $\frac{(1.5 \times 148.0)}{2.5} + \frac{(1.0 \times 150.0)}{2.5} = 148.8$

1

(h) $\frac{24.6}{12}$ $\frac{2.56}{1}$ $\frac{72.8}{35.5}$ = 2.05 : 2.56 : 2.05

Simplest ratio = $\frac{2.05}{2.05} : \frac{2.56}{2.05} : \frac{2.05}{2.05}$

= 1 : 1.25 : 1

1

Whole number ratio (× 4) = 4 : 5 : 4

1

MF = $C_8H_{10}Cl_8$

1

[12]

8 C

[1]

9 (a) Saturated − single bonds only / no double bonds

1

Hydrocarbon − contains carbon and hydrogen (atoms) only

1

(b) $C_{16}H_{34} + 16.5O_2 \longrightarrow 16CO + 17H_2O$

Allow multiples

1

(c) (On combustion) SO_2 produced

Allow equation to produce SO_2. Ignore sulfur oxides.

1

Which causes acid rain

If formula shown it must be correct

M2 is dependent on M1. But if M1 is sulfur oxides, allow M2.

For M2 allow consequence of acid rain or SO_2.

Ignore greenhouse effect and toxic

1

(d) (i) $C_{16}H_{34} \longrightarrow C_8H_{18} + C_2H_4 + 2C_3H_6$

Allow multiples

1

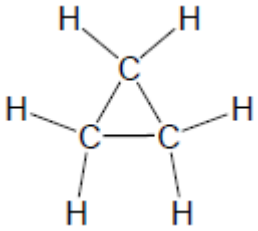
(ii) polypropene / propan(-1 or 2-)ol / propane(-1,2-)diol / isopropanol / propanone / propanal

Accept alternative names

Ignore plastic and polymer

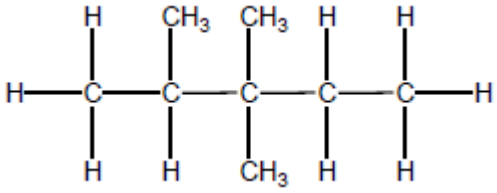
1

(iii)



1

(e)



Allow any unambiguous representation

1

(f) 2,4-dichloro-2,4-dimethylhexane

Only but ignore punctuation

1

[10]

10 (a) (i) **Initiation**

$Br_2 \longrightarrow 2Br\bullet$

First propagation

$Br\bullet + CHF_3 \longrightarrow \bullet CF_3 + HBr$

Second propagation

$Br_2 + \bullet CF_3 \longrightarrow CBrF_3 + Br\bullet$

Termination

$2\bullet CF_3 \longrightarrow C_2F_6$ ***OR*** CF_3CF_3

OR

$2Br\bullet \longrightarrow Br_2$

OR

$Br\bullet + \bullet CF_3 \longrightarrow CBrF_3$

Penalise absence of dot once only

Credit the dot anywhere on the radical

4

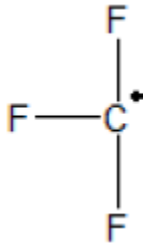
(ii) Ultra-violet / uv / sunlight

OR

T > 100°C OR high temperature

1

(b) (i)



Displayed formula required with the radical dot on carbon

1

(ii) (The) C–Br (bond) breaks more readily / is weaker than (the) C–Cl (bond) (or converse)

OR

The C–Br bond enthalpy / bond strength is less than that for C–Cl (or converse)

*Requires **a comparison** between the two bonds*

Give credit for an answer that suggests that the UV frequency / energy may favour C–Br bond breakage rather than C–Cl bond breakage

Ignore correct references either to size, polarity or electronegativity

Credit correct answers that refer to, for example "the bond between carbon and bromine requires less energy to break than the bond between carbon and chlorine"

1

(iii) **M1**

$Br\bullet + O_3 \longrightarrow BrO\bullet + O_2$

M2

$BrO\bullet + O_3 \longrightarrow Br\bullet + 2O_2$

***M1** and **M2** could be in either order*

Credit the dot anywhere on the radical

Penalise absence of dot once only

Penalise the use of multiples once only

M3 One of the following

They / it / the bromine (atom)

- does not appear in the overall equation
- is regenerated
- is unchanged at the end
- has not been used up
- provides an alternative route / mechanism

3

[10]

11 (a) Crude oil **OR** petroleum

Not petrol.

1

Fractional distillation / fractionation

Not distillation alone.

1

(b) $C_{12}H_{26} + 12.5O_2 \longrightarrow 12CO + 13H_2O$

Allow balanced equations that produce CO_2 in addition to CO.

Accept multiples.

1

(c) (i) M1 Nitrogen and oxygen (from air) react / combine / allow a correct equation

If nitrogen from petrol / paraffin / impurities CE = 0 / 2.

1

M2 at high temperatures

Allow temperatures above 1000 °C or spark.

Not just heat or hot.

M2 dependent on M1.

But allow 1 mark for nitrogen and oxygen together at high temperatures.

1

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

Allow multiples.

1

(iii) $4NO_2 + 2H_2O + O_2 \longrightarrow 4HNO_3$

Allow multiples.

1

(d) (i) C_nH_{2n+2}

Allow C_xH_{2x+2}

CnH2n+2

Allow CxH2x+2

1

(ii) $C_{12}H_{26} \longrightarrow C_6H_{14} + C_6H_{12}$

Only.

1

C_3H_7

Only.

1

Zeolite / aluminosilicate(s)

Ignore aluminium oxide.

1

(iii) Larger molecule / longer carbon chain / more electrons / larger surface area

1

More / stronger van der Waals' forces between molecules

Allow dispersion forces / London forces / temporary induced dipole-dipole forces between molecules.

If breaking bonds, CE = 0 / 2.

1

(e) 2,2,3,3,4,4-hexamethylhexane

Only.

Ignore punctuation.

1

Chain

Ignore branch(ed).

1

(f) Cl_2

Only.

Cl–Cl

Not CL_2 or Cl2 or CL2 or Cl^2 or CL^2.

Ignore Chlorine.

1

[16]

12 (a) (i) **M1 Initiation**

$Cl_2 \longrightarrow 2Cl\bullet$

Penalise absence of dot once only.

M2 First propagation

$Cl\bullet + CHF_3 \longrightarrow CF_3\bullet + HCl$

Penalise + or − charges every time.

M3 Second propagation

$Cl_2 + CF_3\bullet \longrightarrow CClF_3 + Cl\bullet$

Credit $CF_3\bullet$ with the radical dot above / below / to either side.

M4 Termination (must make C_2F_6)

$2\ CF_3\bullet \longrightarrow C_2F_6$ or CF_3CF_3

Mark independently.

4

(ii) ultra-violet / uv / sun light

OR (very) high temperature

OR 500 °C ≤ T ≤ 1000 °C

OR 773 K ≤ T ≤ 1273 K

1

(b) (i) Cl• **OR** chlorine atom / chlorine (free−) radical / Cl (atom)

Not 'chlorine' alone.

Credit 'Cl' alone on this occasion.

1

(ii) **2**O_3 ⟶ **3**O_2

Or multiples.

Ignore state symbols.

If the correct answer is on the line OR clearly identified below some working, then ignore any working.

1

[7]

13 (a) (i) (Compounds with the) same molecular formula

Allow same number and type of atom for M1

Ignore same general formula.

1

But different structural formula / different displayed formula / different structures / different skeletal formula

M2 dependent on M1

Not different positions of atoms / bonds in space.

1

(ii) But-2-ene

Allow but-2-ene.

Allow but 2 ene.

Ignore punctuation.

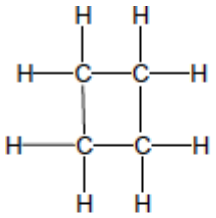
1

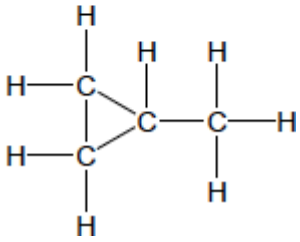
(iii) (2)-methylprop-(1)-ene

Do not allow 2-methyleprop-1-ene.

1

(iv)





Do not allow skeletal formulae.

Penalise missing H and missing C

1

(b) (i) $C_4H_8 + 2O_2 \rightarrow 4C + 4H_2O$

Accept multiples.

1

(ii) Exacerbates asthma / breathing problems / damages lungs / smog / smoke / global dimming

Ignore toxic / pollutant / soot / carcinogen.

Do not allow greenhouse effect / global warming / acid rain / ozone.

1

(c) (i) $C_{16}H_{34}$

Allow $H_{34}C_{16}$

C and H must be upper case.

1

(ii) Jet fuel / diesel / (motor) fuel / lubricant / petrochemicals / kerosene / paraffin / central heating fuel / fuel oil

Ignore oil alone.

Not petrol / bitumen / wax / LPG / camping fuel.

1

(d) (i) $C_8H_{18} + 25NO \rightarrow 8CO_2 + 12.5\ N_2 + 9H_2O$

Accept multiples.

1

(ii) Ir / iridium

OR

Pt / platinum

OR

Pd / palladium

OR

Rh / rhodium

1

[11]

14 (a) **Initiation**

$Cl_2 \longrightarrow 2Cl\bullet$

Penalise absence of dot once only.

First propagation

$Cl\bullet + CH_3Cl \longrightarrow \bullet CH_2Cl + HCl$

Credit the dot anywhere on the radical.

Second propagation

$Cl_2 + \bullet CH_2Cl \longrightarrow CH_2Cl_2 + Cl\bullet$

Termination (must make 1,2-dichloroethane)

$2 \bullet CH_2Cl \longrightarrow CH_2ClCH_2Cl$

Penalise $C_2H_4Cl_2$

4

(b) (i) (chlorine free) radical

Ignore formula.

1

(ii) M1 $Cl\bullet + O_3 \longrightarrow ClO\bullet + O_2$

M2 $ClO\bullet + O_3 \longrightarrow Cl\bullet + 2O_2$

***M1** and **M2** could be in either order.*

Credit the dot anywhere on the radical.

Penalise absence of dot once only.

Individual multiples acceptable but both need to be doubled if two marks are to be awarded.

2

[7]

15 (a) Fractional distillation / fractionation / GLC / gas liquid chromatography

1

(b) C_4H_{10}

Need C_4H_{10} ***and*** *the reason for the mark*

Because it has a higher bp / has stronger IMF / larger molecule / longer chain / larger surface (area)

1

(c) $C_4H_{10} + 6½\ O_2 \longrightarrow 4CO_2 + 5H_2O$

Accept multiples
Ignore state symbols

1

(d) CO_2 or H_2O evolved is a greenhouse gas / CO_2 or H_2O evolved contribute to global warming / the products are greenhouse gases

Ignore climate change

1

(e) $CH_3CH_2CH_2CH_3 + 3.5O_2 \longrightarrow C_2H_2(CO)_2O + 4H_2O$

Accept multiples

Allow with or without a number 1 before the organic molecules

1

(f) (i) $C_2H_5SH + 4.5O_2 \longrightarrow 2CO_2 + 3H_2O + SO_2$

Accept multiples

1

(ii) Calcium oxide / calcium carbonate

Allow any base or alkali
Allow correct formulae

1

Neutralises the SO_2 / acid base reaction / it is a base

Can only score M2 if base or alkali used in M1
Allow M2 if blank in M1

1

(iii) Ethanol contains hydrogen bonding

Breaking covalent bonds CE = 0 / 2

Which is stronger than IMF (VDW / dipole-dipole forces) in ethanethiol / (H bonding) is the strongest IMF

Only award M2 if M1 given, but allow IMF in ethanol are stronger than in ethanethiol for maximum 1 mark

1

(g) (i) (2,2-)dimethylpropane

Ignore punctuation

1

(ii) Because molecule is smaller / less polarisable / has less surface (area) / is more spherical / molecules can't get as close to one another (to feel the vdW forces)

Allow converse answers referring to straight chain isomers CE = 0 / 2 if breaking bonds

1

vdW intermolecular forces or vdW force between molecules are weaker or fewer

Need vdW rather than just IMF

1

(iii) 1 or one

1

(h) (i) C_9H_{20}

$H_{20}C_9$

1

(ii) Thermal (cracking)

If not thermal cracking CE = 0 / 2

1

High pressure AND high temperature

If blank mark on

Allow high P and T

1

OR

Pressure of ≥ 10 atm, ≥ 1 MPa ≥ 1000 kPa

AND temp of 400 °C ≤ T ≤ 1000 °C or 650 K ≤ T≤ 1300 K

Do not allow high heat
If no units for T, then range must be 650 − 1000

1

[17]

16 (a) (i) (Free-) radical substitution

Both underlined words are required

Penalise a correct answer if contradicted by an additional answer

1

(ii) **Initiation**

$F_2 \longrightarrow 2F\bullet$

Penalise absence of dot once only

First propagation

$F\bullet + CH_3F \longrightarrow \bullet CH_2F + HF$

Penalise + or − charges every time

Second propagation

$F_2 + \bullet CH_2F \longrightarrow CH_2F_2 + F\bullet$

Accept dot anywhere on CH_2F radical
Mark independently

Termination (must make 1,2-difluoroethane)

$2 \bullet CH_2F \longrightarrow \underline{CH_2FCH_2F}$

Use of half-headed arrows must be correct to score, but if not correct then penalise once only in this clip

4

(iii) $CH_3CH_3 + \mathbf{5}F_2 \longrightarrow CF_3CHF_2 + \mathbf{5}HF$

(C_2H_6) (C_2HF_5)

1

(b) 1,1,1,2-tetrachloro-2,2-difluoroethane

Accept phonetic spelling eg "fluro, cloro"
Penalise "flouro" and "floro", since ***QoL***

OR

1,2,2,2-tetrachloro-1,1-difluoroethane

Ignore commas and hyphens

1

(c) (i) $\mathbf{2}O_3 \longrightarrow \mathbf{3}O_2$

ONLY this equation or a multiple
Ignore NO over the arrow
Other species must be cancelled

1

(ii) $O + NO_2 \longrightarrow NO + O_2$

ONLY this answer and NOT multiples
Ignore any radical dot on the O atom

1

[9]

17 (a) (i) C_nH_{2n} / C_xH_{2x}

1

(ii) Fractional distillation / GLC / gas liquid chromatography / fractionation

*Do **not** allow cracking / distillation*

1

(b) (i) But-1-ene / but1ene

Ignore hyphens and commas

*Do **not** allow butene-1 / but-2-ene / butane / butane /alkene / C_4H_8 / propene / straight-chain alkene*

1

(ii) A structure of cyclobutane or methyl-cyclopropane

Allow skeletal formula.

1

(c) (i) $C_{15}H_{32} \rightarrow 2C_4H_8 + C_7H_{16}$

Do not accept multiples.

1

(ii) Thermal cracking

Not catalytic cracking or cracking.

1

To produce products that are in greater demand / more valuable / more expensive / more profitable

The (unsaturated) alkene or the (unsaturated) molecule or X produced can be polymerised or can be made into plastics.

Ignore more useful products.

1

(iii) Break (C–C or C–H) bonds

Allow to overcome the activation energy.

Allow to break the carbon chain.

Penalise breaking wrong bonds.

1

(d) (i) H_2

Only.

1

(ii) Fuel / LPG

Allow camping gas, lighter fuel, propellant, refrigerant, cordless appliances.

Do not allow petrol or motor fuel.

Ignore natural gas.

1

(iii) $C_4H_{10} + 2.5O_2 \rightarrow 4C + 5H_2O$

Accept multiples.

1

(iv) SO^2 / sulfur dioxide

If other sulfur oxides, mark on.

1

Calcium oxide / CaO / lime / quicklime

Allow $CaCO_3$ / allow $Ca(OH)_2$ or names.

Allow any solid base.

M2 dependent on M1.

Do not allow limewater.

1

(v) Neutralisation

Allow acid-base reaction.

Allow flue gas desulfurisation / FGD

1

(e) (Molecules) are similar sizes / have similar M_r / have similar number of electrons

Chemical error CE = 0/2 if breaking bonds.

Allow similar number of carbon and hydrogen atoms / similar surface area / similar chain length.

Can accept same number of carbon atoms.

Do not accept same number of H atoms / same number of bonds.

Ignore similar amount of bonds.

1

Similar van der Waals forces <u>between molecules</u> / similar <u>intermolecular</u> forces (IMF)

Not similar incorrect IMF eg dipole-dipole

1

[16]

18 (a) (i) **M1 (could be scored by a correct mathematical expression which must have all ΔH symbols and the $\sum$ or SUM)**

M1 ΔH_r **=** $\Sigma\Delta H_f$ **(products)** - $\Sigma\Delta H_f$ **(reactants)**

OR a correct cycle of balanced equations with 1C, $3H_2$ and $1O_2$

M2 $\Delta H_r = -201 + (-242) - (-394)$
$\Delta H_r = -201 - 242 + 394$
$\Delta H_r = -443 + 394$
(This also scores M1)

M3 = – **49** (kJ mol^{-1})
(Award 1 mark ONLY for + 49)
Correct answer gains full marks
Credit 1 mark ONLY for + 49 (kJ mol^{-1})
For other incorrect or incomplete answers, proceed as follows

- *check for an arithmetic error (AE), which is either a transposition error or an incorrect multiplication; this would score 2 marks (**M1** and **M2**)*
- *If no AE, check for a correct method; this requires either correct cycle of balanced equations with 1C, $3H_2$ and $1O_2$*
  *OR a clear statement of **M1** which could be in words and scores only **M1***

3

(ii) It is an element / elemental
Ignore reference to "standard state"

OR

By definition

1

(b) **M1** (The yield) increases / goes up / gets more

*If M1 is given as "decreases" / "no effect" / "no change" then CE= 0 for clip, but mark on only **M2** and **M3** from a blank M1*

M2 There are more moles / molecules (of gas) on the left / of reactants
OR fewer moles / molecules (of gas) on the right
/ products
OR there are 4 moles /molecules (of gas) on the left and 2 moles / molecules on the right.
OR (equilibrium) shifts / moves to the side with less moles / molecules

*Ignore "volumes", "particles" "atoms" and "species" for **M2***

M3: Can only score M3 if M2 is correct

The (position of) equilibrium shifts / moves (from left to right) to oppose the increase in pressure

*For **M3**, not simply "to oppose the change"*

*For **M3** credit the equilibrium shifts / moves (to right) to lower / decrease the pressure*

(There must be a specific reference to the change that is opposed)

3

(c) **M1** Yield increases goes up

M2 The (forward) reaction / to the right is endothermic OR takes in/ absorbs heat

OR

The reverse reaction / to the left is exothermic OR gives out / releases heat

*If M1 is given as "decrease" / "no effect" / "no change" then CE= 0 for clip, but mark on only **M2** and **M3** from a blank **M1***

Can only score M3 if M2 is correct

M3 The (position of) equilibrium shifts / moves (from left to right) to oppose the increase in temperature **(QoL)**

*For **M3**, not simply "to oppose the change"*

*For **M3**, credit the (position of) equilibrium shifts / moves **(QoL)***

*to absorb the heat **OR***

*to cool the reaction **OR***

to lower the temperature

(There must be a specific reference to the change that is opposed)

3

(d) (i) An activity which has no net / overall (annual) carbon emissions to the atmosphere

OR

An activity which has no net / overall (annual) greenhouse gas emissions to the atmosphere.

OR

There is no change in the total amount / level of carbon dioxide /CO_2 carbon /greenhouse gas present in the atmosphere.

The idea that the carbon /CO_2 given out equals the carbon /CO_2 that was taken in from the atmosphere

1

(ii) $CH_3OH + \mathbf{1}½\ O_2 \longrightarrow CO_2 + \mathbf{2}H_2O$

Ignore state symbols

Accept multiples

1

(iii) $\mathbf{3}H_2 + \mathbf{1}½\ O_2 \longrightarrow \mathbf{3}H_2O$

Ignore state symbols

OR

Accept multiples

$\mathbf{2}H_2 + O_2 \longrightarrow \mathbf{2}H_2O$

Extra species must be crossed through

1

(e) **M1** $q = m\ c\ \Delta T$

Award full marks for correct answer

Ignore the case for each letter

OR $q = 140 \times 4.18 \times 7.5$

M2 = 4389 (J) OR 4.389 (kJ) OR 4.39 (kJ) OR 4.4 (kJ)(also scores M1)

M3 Using 0.0110 mol

therefore ΔH = **– 399** ($kJmol^{-1}$)

OR **– 400**

*Penalise **M3** ONLY if correct numerical answer but sign is incorrect; +399 **gains 2 marks***

*Penalise **M2** for arithmetic error and mark on*

*In **M1**, do not penalise incorrect cases in the formula*

If ΔT = 280.5; score $q = m\ c\ \Delta T$ only

*If c = 4.81 (leads to 5050.5) penalise **M2** ONLY and mark on for **M3** = – 459*

+399 or +400 gains 2 marks

Ignore incorrect units

3

[16]

19 (a) (i) **M1** **Initiation**

$Cl_2 \longrightarrow 2Cl\bullet$

Penalise absence of dot once only.

Penalise + or – charges every time

M2 **First propagation**

$Cl\bullet + CH_2Cl_2 \longrightarrow \bullet CHCl_2 + HCl$

Accept dot anywhere on $CHCl_2$ radical but if the structure is drawn out, the dot must be on the carbon atom. Penalise this error once only

Penalise once only for a line and two dots to show a bond.

M3 **Second propagation**

$Cl_2 + \bullet CHCl_2 \longrightarrow CHCl_3 + Cl\bullet$

Penalise once only for double headed curly arrows

Mark independently

3

(ii) **M1** **Condition**
ultra-violet / uv / sun light

OR high temperature

OR 400°C ≤ T ≤ 900°C

M2 **Type of mechanism**
(free-) radical substitution (mechanism)

2

(b) (i) $CHCl_3 + Cl_2 \longrightarrow CCl_4 + HCl$

Allow X as alternative to CCl_4 only if X is clearly identified as CCl_4

1

(ii) **M1** Trichloromethane / $CHCl_3$ has a C–H bond

OR

X / CCl_4 / it has no C–H bond

***M1** must refer to presence or absence of the C–H bond in a compound*

M2 The infrared spectrum shows
(absorption / peak for C–H in range) **2850 to 3300** (cm^{-1}) is missing

***M2** answer must refer to / imply the spectrum*

Allow the words "dip" OR "spike" OR "low transmittance" as alternatives for absorption.

Ignore references to other absorptions.

2

(c) **M1 a statement about bond breakage / formation of Cl•**

C–Cl / carbon-chlorine bond breakage occurs

OR Cl• / chlorine (free) radical forms

OR correct equation $CHClF_2 \longrightarrow Cl\bullet + \bullet CHF_2$

*Penalise **M1**, if Cl• is formed from Cl_2 as the only reaction or an additional reaction*

Do not penalise an incorrect equation using $CHClF_2$ if correct reference is made to Cl• formation or C–Cl / carbon-chlorine bond breakage

M2 $Cl\bullet + O_3 \longrightarrow ClO\bullet + O_2$

M3 $ClO\bullet + O_3 \longrightarrow Cl\bullet + 2O_2$

***M2** and **M3** either order*

Penalise absence of dot once only.

Accept dot anywhere on ClO radical

M4 $CHClF_2$ / chlorine-containing compounds/ CFCs damage / react with / decrease the ozone layer

OR

this overall decomposition occurs; $2O_3 \longrightarrow 3O_2$

OR

without an ozone layer or with a decreased ozone layer, uv radiation is not being "filtered" / prevented from passing through the atmosphere or there is a concern about an increase in skin cancer etc.

OR

Cl• catalyses the decomposition of ozone / a single Cl• causes (chain) reaction / decomposition of many ozone molecules / ozone layer

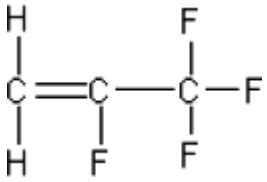
*Award **M4** for the general idea behind the EU justification for banning the use of CFCs as refrigerants*

*Penalise **M4** if overall ozone decomposition equation is incorrect*

Ignore "greenhouse effect", "global warming" etc.

4

(d) (i)



All bonds must be drawn out

1

(ii) 2,3,3,3-tetrafluoropropene / it does not contain chlorine (atoms) / C–Cl (bonds)

Ignore "chlorine molecules"

OR

It does not produce Cl• / does not produce chlorine (free) radical(s)

OR

chlorodifluoromethane does contain chlorine / does produce Cl• / does produce chlorine (free) radical(s)

OR

C–F is too strong and does not break / create radicals

OR

C–F is stronger than C–Cl

1

[14]

20 (a) (i) Crude oil / oil / petroleum

Do not allow 'petrol'

1

(ii) Fractional distillation / fractionation / fractionating

Not distillation alone

1

(b) (i) 5

Allow five / V

1

(ii) Chain (isomerism)

Allow branched chain / chain branched / side chain (isomerism)

Ignore position (isomerism)

Do not allow straight chain / geometric / branched / function

1

(c) (i) $C_{12}H_{26}$ / $H_{26}C_{12}$

Only

1

(ii) Thermal cracking

If not thermal cracking, CE = 0/2

If blank mark on

1

High temperature

Allow 'high heat' for 'high temperature'

(400°C ≤ T ≤ 900°C) or (650 K ≤ T ≤ 1200 K)

Not 'heat' alone

If no T, units must be 650 – 900

and

High pressure (≥ 10 atm, ≥ 1 MPa, ≥1000 kPa)

1

(iii) To produce substances which are (more) in demand / produce products with a high value / products worth more

Ignore 'to make more useful substances'

1

(d) (i) Corrosive or diagram to show this hazard symbol

Ignore irritant, acidic, toxic, harmful

1

(ii) $\left(\frac{120.5}{(86 + 71)} \times 100\right)$

=76.75(%) or 76.8(%)

Allow answers > 3 sig figs

1

(e) 2,2-dichloro-3–methylpentane

Ignore punctuation

Any order

1

C_3H_6Cl

1

[12]

21

(a) (i) $C_8H_{18} + 8\frac{1}{2} O_2 \rightarrow 8CO + 9H_2O$

Accept multiples

1

(ii) Not enough oxygen or air (available for complete combustion) / lack of oxygen or air / too much octane

Ignore poor ventilation, low temp, poor mixing, incomplete combustion

1

(b) (i) $2CO + 2NO \rightarrow 2CO_2 + N_2$

Allow multiples

1

(ii) Pt / Pd / Rh / Ir or names

Apply list principle

1

Big(ger) surface area / increased reaction rate / removes more of the gases / ensures complete reaction

Allow (ceramic) withstands high temperatures

1

(c) (i) Acid rain

Allow consequence of acid rain

Ignore greenhouse gas / global warming / ozone

1

(ii) CaO/ lime / $CaCO_3$ /limestone

Allow chemical names

1

Neutralises the gas or words to that effect/it is basic/ SO_2 is acidic

Allow 'reacts with it' or 'it is alkaline'

Ignore 'absorb'

1

[8]

22 (a) $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$

Accept multiples

Ignore state symbols even if incorrect

1

Not enough oxygen / air

1

CMM / methane is a greenhouse gas / contributes to global warming

Do not allow formation of CO_2 / CO_2 is a greenhouse gas

Apply list principle, eg

CH_4 is a greenhouse gas and toxic = 0

CH_4 is a greenhouse gas and damages ozone = 0

Allow CH_4 and CO_2 are greenhouses gases

Allow collect to use as a fuel so fossil fuels do not run out (as quickly)

1

(b) $CH_3SH + 3O_2 \rightarrow CO_2 + 2H_2O + SO_2$

Accept multiples

Ignore state symbols even if incorrect

1

Calcium oxide is basic (and SO_2 is acidic) /

CaO neutralises SO_2 /

CaO reacts with SO_2 to form gypsum / salt / solid /
$CaSO_4$ / $CaSO_3$

Allow $CaO + SO_2 \rightarrow CaSO_3$

M2 and M3 can only be scored if SO_2 seen somewhere in the answer

1

Acid rain

Allow consequence of acid rain eg increased rusting of iron / fish in lakes die / problems for asthmatics

Apply list principle

Ignore air pollution

1

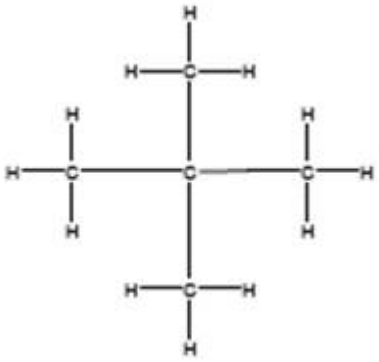
[6]

23 (a) $C_n H_{2n+2}$

Allow x in place of n

1

(b)



Chain

Must show every bond

Allow branched chain

2

(c) C_9H_{20}

Only

1

To break the (C-C and/or C-H) bonds

M2=0 if break C=C

1

To make products which are in greater demand / higher value / make alkenes

Not more useful products

Allow specific answers relating to question

1

(d) $C_5H_{12} + 3O_2 \rightarrow 5C + 6H_2O$

Allow other balanced equations which give C and CO/CO_2

1

Causes global dimming / exacerbates asthma / causes breathing problems / makes visibility poor / smog

Apply list principle

Ignore causes cancer / toxic

1

(e) $\frac{106.5}{143}$ (x 100)

1

74.48%

Allow 74.5%

1

3

Only

1

(f) 2,3-dichloro-3-methylpentane

Ignore punctuation

1

C_3H_6Cl

Only

1

[13]

24 (a) (i) $CH_4 + \mathbf{3}F_2 \longrightarrow CHF_3 + \mathbf{3}HF$

1

(ii) **M1 Initiation**

$F_2 \longrightarrow 2F\bullet$

M2 First propagation

$F\bullet + CHF_3 \longrightarrow \bullet CF_3 + HF$

M3 Second propagation

$F_2 + \bullet CF_3 \longrightarrow CF_4 + F\bullet$

M4 Termination (must make C_2F_6)

$\mathbf{2}\bullet CF_3 \longrightarrow C_2F_6$ or CF_3CF_3

Penalise absence of dot once only.

Radical dot on $\bullet CF_3$ can be anywhere but if the structure is drawn out, the dot must be on the carbon atom. Penalise this error once only.

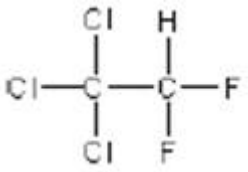
Penalise once only for a line and two dots to show a bond.

Penalise each of "Fl" and lower case F, once only in this clip

4

(b) (i) Displayed formula

e.g.



<u>All bonds</u> must be drawn out.

Ignore bond angles. Penalise "sticks"

1

(ii) **M1** C–Cl bond OR carbon-chlorine bond

M2 chlorine atom OR chlorine (free) radical

M3 **2**$O_3 \longrightarrow$ **3**O_2

M1 NOT carbon-halogen

Penalise incorrect spelling of chlorine once only in this clip

M2 ignore formulae

Ignore Cl_2 or Cl• or ClO• balanced on both sides of the equation

Ignore other equations leading to the overall equation

3

[9]

25 (a) $C_{16}H_{34} + 24.5O_2 \rightarrow 16CO_2 + 17H_2O$

Allow multiples

Ignore state symbols in equation

1

(b) Solidifies/freezes/goes viscous/waxing occurs

Allow does not vapourise/less volatile

Lack of Oxygen = 0

Apply list principle

1

(c) (i) $N_2 + O_2 \rightarrow 2NO$

Allow multiples/Ignore state symbols in equation

1

Spark/(very) high temp/2500 °C – 4000 °C

Ignore pressure/catalyst/low % of oxygen

Not just heat/hot

Apply list principle eg if high temp 150 °C = 0

1

(ii) $2CO + 2NO \rightarrow 2CO_2 + N_2$

Allow multiples/Ignore state symbols in equation

OR

$C_8H_{18} + 25NO \rightarrow 8CO_2 + 12.5\ N_2 + 9H_2O$

Allow other alkane reacting with NO in correctly balanced equation

OR

$C + 2NO \rightarrow CO_2 + N_2$

OR

$2NO \rightarrow N_2 + O_2$

1

Pt/Pd/Rh/Ir

Penalise contradiction of name and symbol

1

(iii) $4NO_2 + 2H_2O + O_2 \rightarrow 4HNO_3$

Allow multiples/Ignore state symbols in equation

1

(d) (i) High temp/

anywhere in range 400 °C – 900 °C/

anywhere in range 670-1200K/high pressure/anywhere in range 5000 kPa up to 8000 kPa/

Not catalyst/heat

1

(ii) $C_{16}H_{34} \rightarrow C_6H_{14} + 2C_4H_8 + C_2H_4$

Or $C_{16}H_{34} \rightarrow C_6H_{14} + C_4H_8 + 3C_2H_4$

Do not allow multiples

Ignore state symbols in equation

1

(iii) Polymers/plastics/named polymer

Allow polyesters or polyamides

Ignore object made from polymer

1

[10]

26 (a) (i) chlorotrifluoromethane

Spelling must be correct but do not penalise "flouro"

Ignore use of 1–

1

(ii) CF_3•

May be drawn out with dot on C

OR if as shown dot may be anywhere

1

(iii) An unpaired/non-bonded/unbonded/free/a single/one/lone electron

NOT "bonded electron" and NOT "paired electron"

NOT "pair of electrons"

NOT "electron s"

Ignore "(free) radical"

1

(b) **M1** Cl• + O_3 → ClO• + O_2

M2 ClO• + O_3 → **2**O_2 + Cl•

Mark independently

Equations could gain credit in either position

The dot can be anywhere on either radical

Penalise the absence of a dot on the first occasion that it is seen and then mark on. Do not make the same penalty in the next equation, but penalise the absence of a dot on the other radical.

Apply the list principle for additional equations

2

(c) (i) (If any factor is changed which affects an equilibrium), the (position of) equilibrium will shift/move so as to oppose the change.

OR

(When a system/reaction in equilibrium is disturbed), the equilibrium shifts/moves in a direction which tends to reduce the disturbance

Must refer to equilibrium

Ignore reference to "system" alone

A variety of wording will be seen here and the key part is the last phrase.

An alternative to shift/move would be the idea of changing/altering the position of equilibrium

1

(ii) **M1** The (forward) reaction/to the right is endothermic or takes in heat

OR The reverse reaction/to the left is exothermic or gives out heat

M2 The equilibrium moves/shifts to oppose the increase in temperature

M2 depends on a correct statement for M1

For M2 accept

The equilibrium moves/shifts

- *to take in heat/lower the temperature*
- *to promote the endothermic reaction and take in heat/ lower the temperature*
- *to oppose the change and take in heat/lower the temperature*

(leading to the formation of more ozone)

2

(d) Any one of

- Pentane does not contain chlorine OR C–Cl (bond)
- Pentane is chlorine-free
- Pentane does not release chlorine (atoms/radicals)

Ignore reference to F OR C–F OR halogen

Ignore "Pentane is not a CFC"

Ignore "Pentane is a hydrocarbon"

Ignore "Pentane only contains C and H"

Ignore "Pentane is C_5H_{12}"

1

[9]

27 (a) (i) (Free-) radical substitution

Both words needed

1

(ii) UV light/Ultra-violet light/sunlight
OR high temperature/150 °C ≤ T ≤ 500 °C

1

(iii) Propagation (Step)

Ignore "first" or "second"

Accept phonetic spelling

1

(iv) **M1** Termination (Step)

M2 **2**$CH_3CH_2CH_2\bullet \longrightarrow C_6H_{14}$

In M2

C_6H_{14} may be drawn out as $CH_3CH_2CH_2CH_2CH_2CH_3$

The dot may be anywhere around the terminal CH_2 on the radical

Accept $C_3H_7\bullet$ with dot anywhere

Penalise the absence of any radical dot

2

(v) $C_3H_8 + \mathbf{8}Br_2 \longrightarrow C_3Br_8 + \mathbf{8}HBr$

Or multiples

1

(b) (i) **M1** Double bonds are

electron-rich

OR <u>electron pair donors</u>

OR centres of <u>electron density</u>.

M2 Bromine <u>becomes polarised/becomes polar</u>

OR forms an <u>induced dipole</u>

OR <u>becomes δ+/δ–</u>

M1 QoL – require <u>one</u> of these terms

Ignore "(very) negative" and "nucleophile" as applied to the double bond.

Penalise M2 for ion formation from bromine

For M2, do not credit dipole formation <u>solely</u> as a consequence of electronegativity

2

(ii) <u>Electrophilic addition</u>

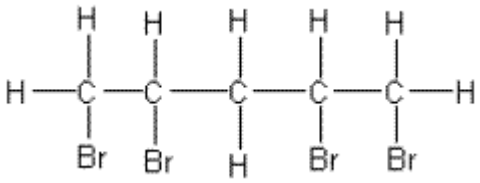
Both words needed

Accept phonetic spelling

1

(iii) Structure for 1,2,4,5-tetrabromopentane, for example
$BrCH_2CHBrCH_2CHBrCH_2Br$

OR



Must be clear that they have drawn 1,2,4,5-tetrabromopentane and does NOT need to be displayed

Credit use of "sticks" for each C-H bond

1

(c) +

M1 Structure of CH_3CHCH_3

M2 (Secondary) Carbocation OR (secondary) carbonium ions

Mark independently

For M1 the positive charge must be on the central carbon atom

Penalise bond to positive charge

Penalise answers which show more than the correct carbocation e.g. the mechanism, unless the intermediate is clearly identified

Credit use of "sticks" for each C-H bond

For M2, penalise "primary" or "tertiary"

2

[12]

28 (a) O = 74.1%

1

$\frac{25.9}{14}$ $\frac{74.1}{16}$

If atomic numbers or molecular masses are used lose M2

1

1.85 4.63
1 2.5
N_2O_5

1

This ratio alone will not score the final mark. (It would get 2)
Allow 3 marks for N_2O_5

(b) Toxic/poisonous/forms an acidic gas/forms NO_2 which is acidic/ respiratory irritant/forms HNO_3 when NO reacts with water and oxygen/ triggers asthma attacks/greenhouse gas/photochemical smog/ contributes to global warming/formation of acid rain

ignore NO is an acidic gas or NO is acidic in water
Not references to ozone layer

1

(c) $2NO + O_2 \rightarrow 2NO_2$

Accept multiples or fractions of equation
Ignore wrong state symbols

1

(d) Nitrogen/N_2 and oxygen/O_2 combine/react

QWC (not N and O combine)
Not nitrogen in fuel
Allow $N_2 + O_2 \rightarrow 2NO$ for M1 only

1

spark/high temperature/2500-4000 °C

1

(e) $2NO + 2CO \rightarrow N_2 + 2CO_2$

OR

$2NO \rightarrow N_2 + O_2$

Accept multiples or fractions of equation
Ignore wrong state symbols
Allow $C_8H_{18} + 25NO \rightarrow 8CO_2 + 12.5N_2 + 9H_2O$

1

[8]

29 (a) (i) $C_4H_{10} + 6\frac{1}{2} O_2 \rightarrow 4CO_2 + 5H_2O$

Allow multiples

1

(ii) insufficient oxygen/low temperature/poor mixing of butane and air

Allow insufficient air
Allow lack or oxygen/air
Do not allow no oxygen
Not incomplete combustion

1

(b) (i) Sulfur dioxide/SO_2

Allow sulfur trioxide/SO_3

(allow spelling of sulphur to be sulphur)

1

(ii) It is basic/the gas (SO_2) is acidic

Idea of neutralisation
It = calcium oxide

1

(iii) bigger surface area to react

Do not allow cheaper

1

[5]

30 (a) (Different) boiling points

Ignore mp's, references to imf, different volatilities

1

(b) (i) Compound which have the same <u>molecular</u> formula

Accept same no and type of atom for M1
But If same (chemical) formula M1 = 0 but allow M2
If empirical formula CE = 0/2

1

but different structures/different structural formulae/different displayed formulae

M2 dependent on M1

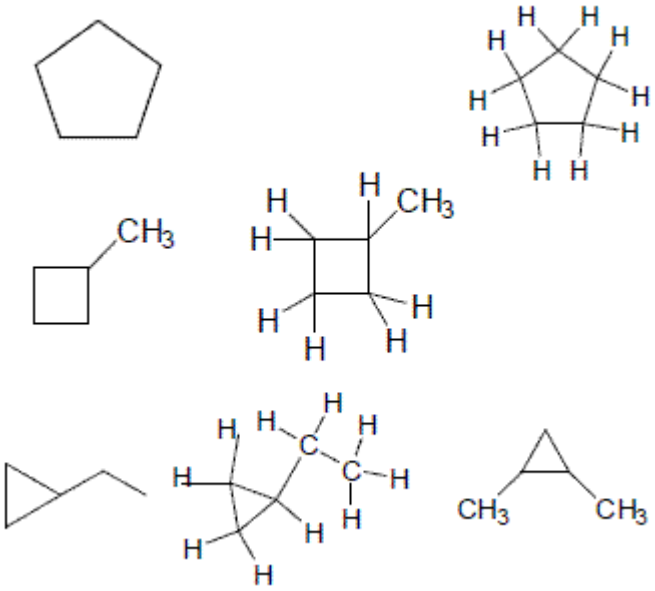
1

(ii) 3-methylbut-1-ene

only
ignore commas and hyphens

1

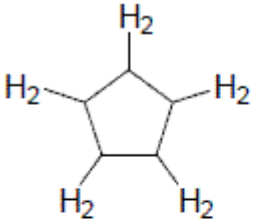
(iii)



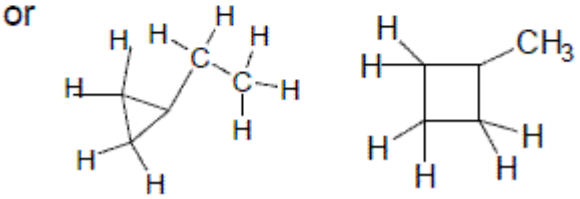
Allow any correct structure with a cyclic alkane

1

Do not allow



or



i.e with an H missing on one C

(c) $C_{13}H_{28}$

only

1

<u>Making</u> plastics/used to make polymers or polythene/used to make antifreeze/make ethanol/ripening fruit/any named additional polymer

*not used **as** a plastic/polymer/antifreeze*
not just 'polymers' – we need to see that they are being made

1

[6]

31 (a) (i) single (C-C) bonds <u>only</u>/no double (C=C) bonds

1

Allow all carbon atoms bonded to four other atoms
Single C-H bonds only = 0
C=H CE

C and H (atoms) only/purely/solely/entirely

Not consists or comprises
Not completely filled with hydrogen
CH molecules = CE
Element containing C and H = CE

1

(ii) C_nH_{2n+2}

Formula only
C_xH_{2x+2}

1

(b) (i) $C_5H_{12} + 8O_2 \rightarrow 5CO_2 + 6H_2O$

Accept multiples
Ignore state symbols

1

(ii) gases produced are greenhouse gases/contribute to Global warming/effect of global warming/climate change

Allow CO_2 or water is greenhouse gas/causes global warming
Acid rain/ozone CE = 0

1

(c) carbon

Allow C
Allow soot

1

(d) (i) $C_9H_{20} \rightarrow C_5H_{12} + C_4H_8$

OR

$C_9H_{20} \rightarrow C_5H_{12} + 2C_2H_4$

Accept multiples

1

(ii) Plastics, polymers

Accept any polyalkene/haloalkanes/alcohols

1

(iii) so the <u>bonds</u> break ***OR*** because the <u>bonds</u> are strong

IMF mentioned = 0

1

(e) (i) 1,4-dibromo-1-chloropentane/1-chloro-1,4-dibromopentane

Ignore punctuation

1

(ii) Chain/position/positional

Not structural or branched alone

1

[11]

32 (a) Functional group (isomerism)

1

(b)

M1 Tollens' (reagent) (*Credit ammoniacal silver nitrate* **OR** *a description of making Tollens'*) (*Ignore either $AgNO_3$ or $[Ag(NH_3)_2^+]$ or "the silver mirror test" on their own, but mark M2 and M3*)	**M1** Fehling's (solution) or Benedict's solution (*Ignore $Cu^{2+}(aq)$ or $CuSO_4$ on their own, but mark on to M2 and M3*)
M2 silver mirror **OR** black solid/precipitate *(NOT silver precipitate)*	**M2** Red solid/precipitate (*Credit orange or brown solid*)
M3 (stays) colourless or no change or no reaction	**M3** (stays) blue or no change or no reaction

Mark on from an incomplete/incorrect attempt at the correct reagent, penalising M1

No reagent, CE=0

Allow the following alternatives
M1 *(acidified) potassium dichromate(VI) (solution)*
M2 *(turns) green*
M3 *(stays) orange/no change*
OR
M1 *(acidified) potassium manganate(VII) (solution)*
M2 *(turns) colourless*
M3 *(stays) purple/no change*

For M3
Ignore "nothing (happens)"
Ignore "no observation"

3

(c) (Both have) C=O ***OR*** a carbonyl (group)

1

(d) (i) (Free-) radical substitution ONLY

Penalise "(free) radical mechanism"

1

(ii) **Initiation**

$Cl_2 \rightarrow 2Cl\bullet$

Penalise absence of dot once only.

First propagation

$Cl\bullet + CH_3CH_2CH_3 \rightarrow \bullet CH_2CH_2CH_3 + HCl$

OR C_3H_8

Penalise incorrect position of dot on propyl radical once only.

Penalise $C_3H_7\bullet$ once only

Second propagation

$Cl_2 + \bullet CH_2CH_2CH_3 \rightarrow CH_3CH_2CH_2Cl + Cl\bullet$

OR

C_3H_7Cl

Accept $CH_3CH_2CH_2\bullet$ with the radical dot above/below/to the side of the last carbon.

Termination (must make C_6H_{14})

$2 \bullet CH_2CH_2CH_3 \rightarrow C_6H_{14}$ or $CH_3CH_2CH_2CH_2CH_2CH_3$

Use of the secondary free radical might gain 3 of the four marks

4

(e) M_r = 44.06352 (for propane)

M_r = 43.98982 (for carbon dioxide)

Mark independently

M1 a correct value for both of these M_r values.

M2 a statement or idea that two peaks appear (in the mass spectrum)

OR

two molecular ions are seen (in the mass spectrum).

2

[12]

33 (a) (i) Covalent;

If not covalent CE = 0.
If blank, mark on.

1

Shared pair of electrons (one from each atom);

Not shared electrons.

1

(ii) Hydrogen bonds / H bonds;

Not just hydrogen.

1

Van der Waals/London/dispersion forces/temporary induced dipole;

1

(b) Showing all the lone pairs on both molecules;

Allow showing both lone pairs on the O involved in the H-bond.

1

Showing the partial charges on O and H on both molecules;

Allow showing both partial charges on the O and H of the other molecule involved in the H bond.

1

Showing the Hydrogen bond from the lone pair on O of one molecule to the delta + on the H of the other molecule;

1

(c) (i) $C_2H_5OH + 3O_2 \rightarrow 2CO_2 + 3H_2O$;

Accept multiples.
Allow C_2H_6O.

1

(ii) CO is (produced which is) toxic/ poisonous/C (may be produced) which is toxic/ C is a respiratory irritant/ C (particles) exacerbate asthma/C causes global dimming/ smog;

Must relate to C or CO.
Any mention of SO_2 NO_2 or other pollutants CE = 0.

1

(iii) More fuel needed (which costs more)/Wastes fuel/ less fuel burnt (so need more to buy more)/engine gets sooty so need to pay for engine to be cleaned/Have to fit catalytic converter;

Not just costs more.
Not engine gets sooty unless qualified.

1

(d) (i) (React) with CaO/ calcium oxide/quicklime/lime;

Accept $CaCO_3$/ calcium carbonate/limestone.

Not chalk.

1

All the sulfur dioxide may not react with the CaO or $CaCO_3$ / may not have time to react/ incomplete reaction;

Accept incomplete reaction.

1

(ii) Occupies a (much) smaller volume;

Not easier to store or transport.

1

[13]

34 (a) **M1** (Free-) **radical substitution**

Both words needed

1

M2 $Cl_2 \rightarrow 2Cl\bullet$

1

M3 $Cl\bullet + CH_4 \rightarrow \bullet CH_3 + HCl$

1

M4 $Cl_2 + \bullet CH_3 \rightarrow CH_3Cl + Cl\bullet$

1

M5 $CH_4 + 3Cl_2 \rightarrow CHCl_3 + 3HCl$

Penalise the absence of a radical dot once only

***Ignore termination steps except, if and only if <u>both</u>** M3 and M4 do not score, then accept for one mark*

$Cl\bullet + \bullet CH_3 \rightarrow CH_3Cl$

1

(b) **M1** UV (light)/ sunlight / light / UV radiation

M2 C–Cl or carbon-chlorine bond breakage
OR
homolysis of C–Cl
OR
equation to show a chlorine-containing organic compound forming two radicals

For M1 and M2, ignore use of Cl_2, but credit UV and C–Cl bond breakage if seen

1

M3 $Cl\bullet + O_3 \rightarrow ClO\bullet + O_2$

1

M4 $ClO\bullet + O_3 \rightarrow Cl\bullet + 2O_2$

Ignore other equations
Penalise the absence of a radical dot once only
Accept radical dot anywhere on either radical.

1

M5 Any **one** from

- Combination $2O_3 \rightarrow 3O_2$
- Stated that Cl• / chlorine atom is regenerated / not used up
- Stated that the Cl• / chlorine atom is unaffected by the process.

1

For M5 accept Cl• on both sides of the equation

M6 Stated that the role of the Cl• / chlorine atom is to find an alternative route ***OR*** lower E_a / activation energy

1

(c) **M1** Halothane contains C–Cl / Cl

OR

Desflurane does not contain C–Cl bonds / Cl

OR

Desflurane contains C–F / F as the only halogen

Mark independently.
For M1, credit the idea that desflurane contains C–F bonds that are difficult to break OR that halothane contains C–Cl bonds which are easy to break.

1

M2 Desflurane / molecules that have fluorine as the only halogen, cause no damage / do not deplete / do not react with the ozone (layer)

OR

Halothane / chlorine-containing molecules, damage / deplete / react with the ozone (layer)

1

[13]

35 (a) Single bonds only /no double or multiple bonds;

1

Contains carbon and hydrogen only;

C and H only
not C and H molecules

1

Alkanes;

1

(b) (1) Fractions or hydrocarbons or compounds have different boiling points/ separation depends on bp;

Ignore mp and vdw

1

(2) bp depends on size/ M_r/ chain length;

If refer to bond breaking/cracking/ blast furnace/oxygen/air 2 max

1

(3) Temp gradient in tower or column / cooler at top of column or vice versa;

QWC

1

(4) Higher bp / larger or heavier molecules at bottom (of column) or vice versa;

Not increasing size of fraction
Not gases at top

1

(c) Large molecules or compounds or long chain hydrocarbons (broken) into smaller molecules or compounds or smaller chain hydrocarbons;

QWC

1

Zeolite or aluminosilicate (catalyst);

1

$C_{14}H_{30} \rightarrow C_8H_{18} + C_6H_{12}$;

Only

1

Smaller chain molecules are in more demand or have higher value or vice versa;

Insufficient to say more useful/have more uses

1

(d) $C_8H_{18} + 8½\ O_2 \rightarrow 8CO + 9H_2O$;

Allow multiples

1

Rh/ Pd/Pt/Ir or in words;

Penalise contradiction of name and symbol

1

$2CO + 2NO \rightarrow 2CO_2 + N_2$ / $2CO + O_2 \rightarrow 2CO_2$;

Allow multiples

1

Greenhouse gas/ absorbs infrared radiation;

1

(e) car less powerful/ car stops/ reduced performance/ won't run smoothly/ can't accelerate;

Not incomplete combustion or bad effect on engine

Not doesn't go as far.

1

Test it (before sale) /Quality control etc;

1

(f) (compounds with) same molecular formula / same no and type of atoms;

Not atoms/elements with same molecular formula.
If same <u>chemical</u> formula, can allow M2

1

And different structure/ structural formula;

M2 consequential on M1
Allow displayed formula for M2

1

2,2,4-trimethylpentane;

Only (but allow numbers in any order)

1

[20]

36 (a) (i) Prevents release of toxic CO
More energy efficient (releases more energy on combustion)

1

(ii) $C_6H_{14} + 6.5O_2 \rightarrow 6CO + 7H_2O$

1

Suitable product eg CO or C

1

Balanced equation

1

(iii) Detect CO gas or C (soot or particles) in exhaust gases

1

(b) $CH_3CH_2CH_2CH(CH_3)_2$

1

2-methylpentane

1

$CH_3CH_2CH(CH_3)CH_2CH_3$ etc

1

(c) (i) $CH_3CH_2CH_2CH=CH_2$

1

(ii) Alumino silicate etc

1

(iii) Can be made into polymers (or alcohols etc)

1

(d) (i) % atom economy = mass CH_2Cl_2/total mass reactants = 85 × 100/158

1

= 53.8%

1

(ii) Because expensive chlorine is not incorperated into desired product Raise money by selling HCl

1

[14]