

AQA A-LEVEL CHEMISTRY • 7405

CHEMISTRY



EXAM QUESTION PACK

3.3.2 ALKANES

SCORE

/226

PERCENTAGE

%

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Q1.

This question is about the reactions of alkanes.

- (a) Alkanes can be used as fuels.

Give an equation for the combustion of heptane (C_7H_{16}) in an excess of oxygen.

_____ (1)

- (b) Heptane can be obtained from the catalytic cracking of hexadecane ($C_{16}H_{34}$) at a high temperature.

Identify a suitable catalyst for this process.

Give **one** condition other than high temperature.

Give an equation for the catalytic cracking of one molecule of hexadecane to produce one molecule of heptane, one molecule of cyclohexane and one other product.

Catalyst _____

Condition _____

Equation _____

_____ (3)

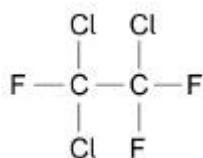
- (c) Alkanes can be used in free-radical substitution reactions to produce halogenoalkanes.

Give equations for the propagation steps in the reaction of butane to form 2-chlorobutane.

(2)

- (d) Chlorofluorocarbons (CFCs) are a group of halogenoalkanes currently banned in many countries. They cannot be used as solvents or refrigerants because of their effect on the environment.

The structure of a CFC is shown.



Identify the radical produced from this CFC that is responsible for the depletion of ozone in the atmosphere.

Explain, with the aid of equations, why a single radical can cause the decomposition of many molecules of ozone.

Radical _____

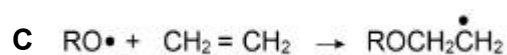
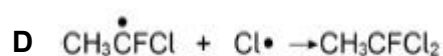
Explanation _____

(4)

(Total 10 marks)

Q2.

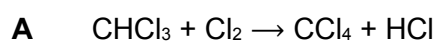
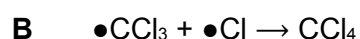
Which equation represents a termination step?

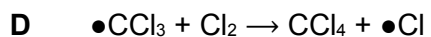
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(Total 1 mark)

Q3.

Which equation is a propagation step in the conversion of trichloromethane into tetrachloromethane by reaction with chlorine in the presence of ultraviolet light?

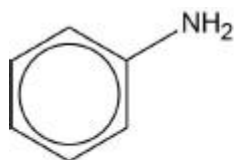
☐☐☐



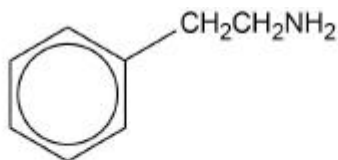
(Total 1 mark)

Q4.

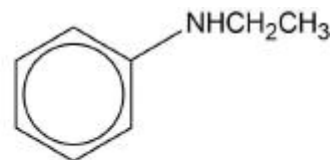
This question is about the three amines, **E**, **F** and **G**.



E



F



G

- (a) Amines **E**, **F** and **G** are weak bases.

Explain the difference in base strength of the three amines and give the order of increasing base strength.

(6)

- (b) Amine **F** can be prepared in a three-step synthesis starting from methylbenzene.

Suggest the structures of the two intermediate compounds.

For each step, give reagents and conditions only. Equations and mechanisms are **not** required.

Q5.

Which of the following mechanisms does **not** occur in reactions of bromoethane?

- | | | |
|----------|---------------------------|--------------------------|
| A | Electrophilic addition | ☐ |
| B | Elimination | ☐ |
| C | Nucleophilic substitution | ☐ |
| D | Radical substitution | ☐ |

(Total 1 mark)

Q6.

Which species is produced in a propagation step during the reaction of propane with an excess of chlorine in the presence of UV light?

- | | | |
|----------|-----------------------------------|--------------------------|
| A | $\text{H}\cdot$ | ☐ |
| B | $\text{C}_3\text{H}_5\text{Cl}$ | ☐ |
| C | $\text{C}_3\text{H}_6\text{Cl}_2$ | ☐ |
| D | C_6H_{14} | ☐ |

(Total 1 mark)

Q7.

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

- | | | |
|----------|-----------------------------------|--------------------------|
| A | $\text{C}_2\text{H}_4\text{Br}_2$ | ☐ |
| B | HBr | ☐ |
| C | H_2 | ☐ |
| D | C_4H_{10} | ☐ |

(Total 1 mark)

Q8.

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 $L = 6.022 \times 10^{23} \text{ mol}^{-1}$)

(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)

Q9.

Haloalkanes are used as refrigerants, solvents and anaesthetics.

- (a) Trichloromethane (CHCl_3) is a haloalkane that can be formed by heating a mixture of chloromethane (CH_3Cl) and chlorine.

- (i) Write an overall equation for the formation of trichloromethane by the reaction of chloromethane with chlorine.

(1)

- (ii) Name the mechanism for this formation of trichloromethane.

(1)

- (iii) Dichloromethane (CH_2Cl_2) is an intermediate in this formation of trichloromethane.

Write an equation for each of the following steps in the mechanism for the reaction of dichloromethane with chlorine.

Initiation step

First propagation step

Second propagation step

A termination step leading to the formation of a compound with formula $C_2H_2Cl_4$

(4)

- (b) Chlorotrifluoromethane ($CClF_3$) is used as a refrigerant, but is being phased out due to concerns about ozone depletion in the upper atmosphere. In the upper atmosphere, $CClF_3$ decomposes in the presence of UV light forming a reactive intermediate that catalyses the decomposition of ozone.

- (i) Write an equation to show how $CClF_3$ decomposes to form the reactive intermediate.

(1)

- (ii) Write two equations to show how this reactive intermediate is involved in catalysing the decomposition of ozone.

1. _____

2. _____

(2)

(Total 9 marks)

Q10.

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

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



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, CHF₃ has replaced CClF₃ because of concerns about ozone depletion.

- (i) Identify the species formed from CClF₃ 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.

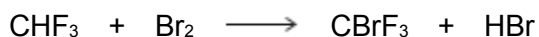
(1)

(Total 7 marks)

Q11.

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.



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 CHF₃ with Br₂

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.



(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



Write **two** equations to show how bromine atoms ($\text{Br}^\bullet$) 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)

Q12.

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



- (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 the decomposition of ozone.

Equation 1 _____

Equation 2 _____

(2)

(Total 7 marks)

Q13.

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 ($\text{CCl}_3\text{CF}_2\text{Cl}$) has been banned because of concerns about ozone depletion.

Give the IUPAC name for $\text{CCl}_3\text{CF}_2\text{Cl}$

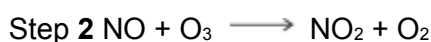
(1)

- (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.



Q14.

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 _____

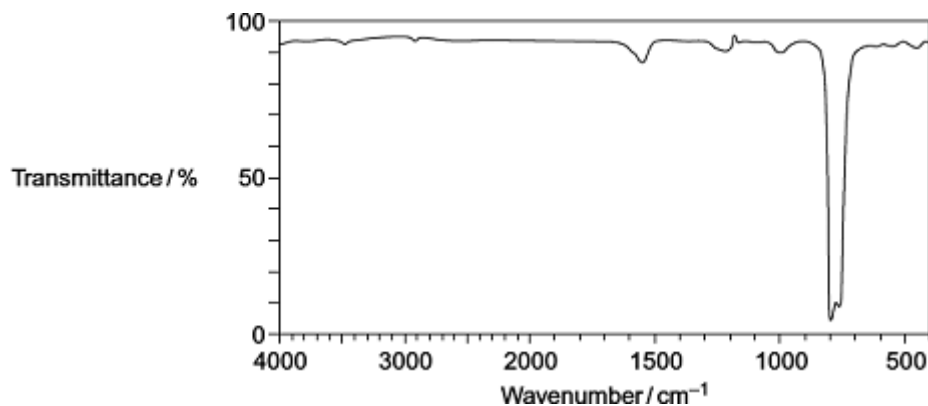
(2)

- (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.

(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.

(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.

(1)

(Total 14 marks)

Q15.

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)

Q16.

- (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.



- (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.

(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)

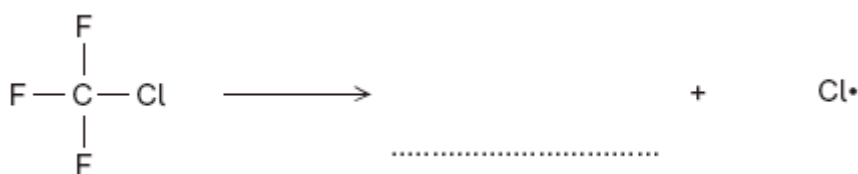
Q17.

Oxygen and ozone (O₃) 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 CF₃Cl

- (a) (i) Give the IUPAC name of CF₃Cl

(1)

- (ii) Complete the following equation that shows the formation of a chlorine atom from a molecule of CF₃Cl



(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.



- (i) State Le Chatelier's principle.

(1)

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

(2)

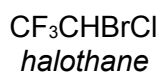
- (d) Chemists supported the legislation to ban the use of CFCs. Modern refrigerators use pentane rather than CFCs as refrigerants. With reference to its formula, state why pentane is a more environmentally acceptable refrigerant.

(1)

(Total 9 marks)

Q18.

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*.



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).

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

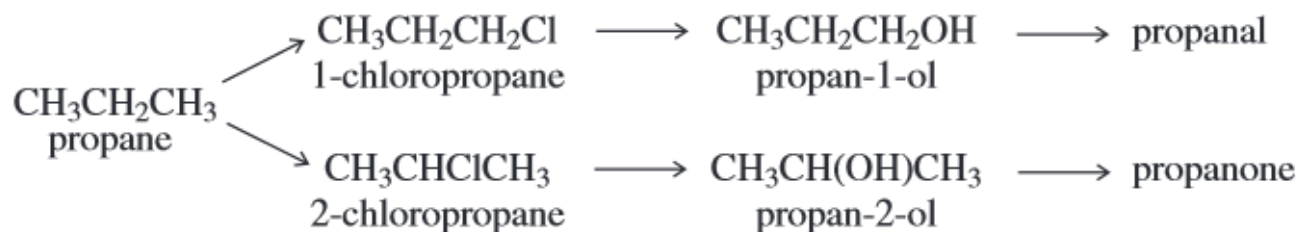
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-
-
-
-

(Total 13 marks)

Q19.

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 1-chloropropane ($\text{CH}_3\text{CH}_2\text{CH}_2\text{Cl}$).

Initiation step

First propagation step

Second propagation step

A termination step to form a molecule with the empirical formula C₃H₇

(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 the sample contains both of these gases.

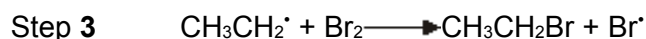
Atom	Precise relative atomic mass
¹² C	12.00000
¹ H	1.00794
¹⁶ O	15.99491

(2)

(Total 12 marks)

Q20.

The reaction of bromine with ethane is similar to that of chlorine with ethane. Three steps in the bromination of ethane are shown below.



- (a) (i) Name this type of mechanism.

- (ii) Suggest an essential condition for this reaction.

- (iii) Steps 2 and 3 are of the same type. Name this type of step.

- (iv) In this mechanism, another type of step occurs in which free-radicals combine. Name this type of step. Write an equation to illustrate this step.

Type of step

Equation _____

(5)

- (b) Further substitution in the reaction of bromine with ethane produces a mixture of liquid organic compounds.

- (i) Name a technique which could be used to separate the different compounds in this mixture.

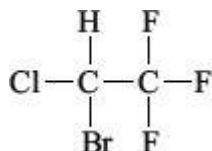
- (ii) Write an equation for the reaction between bromine and ethane which produces hexabromoethane, C_2Br_6 , by this substitution reaction.

(2)

- (c) The compound 1,2-dibromo-1,1,2,2-tetrafluoroethane is used in some fire extinguishers. Draw the structure of this compound.

(1)

- (d) Halothane is used as an anaesthetic and has the following structure.



- (i) Give the systematic name of *halothane*.

- (ii) Calculate the M_r of halothane.

- (iii) Calculate the percentage by mass of fluorine in halothane.

(3)

(Total 11 marks)

Q21.

- (a) Dichloromethane, CH_2Cl_2 , is one of the products formed when chloromethane, CH_3Cl , reacts with chlorine.

- (i) Name the type of mechanism involved in this reaction and write an equation for each of the steps named below.

Name of type of mechanism _____

Initiation step

First propagation step

Second propagation step

- (ii) Write an overall equation for the formation of dichloromethane from chloromethane.

(5)

- (b) A compound contains 10.1% carbon and 89.9% chlorine by mass. Calculate the molecular formula of this compound, given that its relative molecular mass (M_r) is 237.0

(3)

- (c) Suggest the formulae of two bromine-containing organic compounds formed when dibromomethane, CH_2Br_2 , reacts with bromine.

Compound 1

Compound 2

(2)

(Total 10 marks)

Q22.

Chlorination of ethane follows a free-radical substitution mechanism. This mechanism is similar to that which occurs when methane is chlorinated. The overall equation for the reaction of ethane to form chloroethane is given below.



State the conditions and outline a mechanism for this reaction. Show how butane can be formed in this reaction.

(Total 5 marks)

Q23.

The mechanism for the reaction of methane with fluorine is a free-radical substitution similar to the chlorination of methane.

- (a) Outline the following steps in the mechanism for the reaction of methane with fluorine to form fluoromethane, CH_3F

Initiation step

First propagation step

Second propagation step

A termination step

(4)

- (b) Write an overall equation for the reaction of fluorine with fluoromethane to form tetrafluoromethane.

(1)

(Total 5 marks)

Q24.

- (a) Bromomethane, CH_3Br , can be formed by a reaction between bromine and methane.

The mechanism for this reaction is similar to the mechanism for the chlorination of methane.

- (i) Name the mechanism for this reaction.

- (ii) Give the name of, and state an essential condition for, the first step in the mechanism for this reaction.

Name

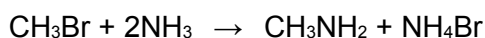
Essential condition

- (iii) Write an equation for a termination step in the mechanism for this reaction which gives ethane as a product.

- (iv) Bromomethane can undergo further substitution. Write an overall equation for the reaction between bromomethane and bromine in which dibromomethane is formed.

(5)

- (b) Bromomethane reacts with the nucleophile ammonia according to the following equation.



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

- (ii) Name the organic product of this reaction.

- (iii) Outline a mechanism for this reaction.

(6)
(Total 11 marks)

Q25.

(a) Chloromethane can be made by the reaction of chlorine with methane.

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

(ii) Name the mechanism for this reaction.

(iii) Further substitution can occur during this reaction. Identify the main organic product when a large excess of chlorine is used in this reaction.

(3)

(b) Ethanenitrile can be made by reacting chloromethane with potassium cyanide.

(i) Write an equation for this reaction.

(ii) Name the mechanism for this reaction.

(iii) Explain, in terms of bond enthalpies, why bromomethane reacts faster than chloromethane with potassium cyanide.

(3)

(c) Ethanenitrile can be hydrolysed to a carboxylic acid by heating it under reflux with a dilute acid. Identify the carboxylic acid formed in this reaction.

(1)

- (d) Chloromethane can react with ammonia to produce a primary amine.
- (i) What feature of the chloromethane molecule makes it susceptible to attack by an ammonia molecule?
- _____
- (ii) Name the amine produced in this reaction.
- _____
- (iii) Outline a mechanism for this reaction.

(6)
(Total 13 marks)

Q26.

When chlorine reacts with trichloromethane, tetrachloromethane, CCl_4 , is formed.

- (a) (i) Write the overall equation for this reaction.

- (ii) State **one** essential condition for this reaction.

(2)

- (b) The mechanism for the chlorination of trichloromethane is free-radical substitution, which proceeds by a series of steps. Write equations for the steps named below in this chlorination.

Initiation step

First propagation step

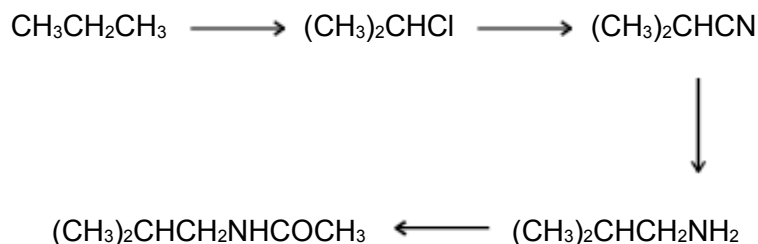
Second propagation step

A termination step

(4)
(Total 6 marks)

Q27.

Which one of the following types of reaction mechanism is **not** involved in the above sequence?



- A free-radical substitution
- B nucleophilic substitution
- C elimination
- D nucleophilic addition-elimination

(Total 1 mark)

Q28.

In the presence of ultraviolet light, methane and chlorine react to form a number of chlorine-containing products, including CH_2Cl_2 and CHCl_3

- (i) Write an equation for the initiation step in the mechanism for this reaction.

- (ii) Write the overall equation for the formation of CHCl_3 from CH_2Cl_2 and Cl_2

- (iii) Write equations for the two propagation steps by which CH_2Cl_2 is converted into CHCl_3

Equation 1 _____

Equation 2 _____

- (iv) Suggest what effect increasing the intensity of the ultraviolet light would have on the rate of the reaction between methane and chlorine. Explain your answer.

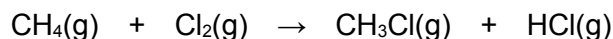
Effect on rate _____

Explanation _____

(Total 6 marks)

Q29.

The equation below represents a reaction between methane and chlorine.



- (a) State an essential condition required for this reaction to occur. Explain why this condition is essential.

Condition _____

Explanation _____

(2)

- (b) (i) State the type of mechanism involved in the above reaction.

- (ii) Name the three types of step involved in this mechanism.

Step 1 _____

Step 2 _____

Step 3 _____

(4)

- (c) In addition to CH_3Cl , compounds such as CH_2Cl_2 and $\text{CH}_3\text{CH}_2\text{Cl}$ may also be formed when chlorine reacts with methane.

- (i) Write equations for the two steps in the mechanism by which CH_2Cl_2 is formed from CH_3Cl

Equation 1 _____

Equation 2 _____

- (ii) Write an equation to represent a step in the mechanism in which $\text{CH}_3\text{CH}_2\text{Cl}$ is formed.

(3)

(Total 9 marks)

Q30.

Which one of the following mechanisms is **not** involved in the reaction sequence below?



- A** electrophilic addition
B electrophilic substitution
C nucleophilic substitution
D free-radical substitution

(Total 1 mark)

Q31.

Which one of the following reactions involves nucleophilic addition?

- A** $\text{CH}_3\text{CH}=\text{CH}_2 + \text{HBr} \rightarrow \text{CH}_3\text{CHBrCH}_3$
- B** $\text{CH}_3\text{CH}_2\text{CH}_3 + \text{Cl}_2 \rightarrow \text{CH}_3\text{CHClCH}_3 + \text{HCl}$
- C** $\text{CH}_3\text{CH}_2\text{CH}_2\text{Br} + \text{NaOH} \rightarrow \text{CH}_3\text{CH}_2\text{CH}_2\text{OH} + \text{NaBr}$
- D** $\text{CH}_3\text{CH}_2\text{CHO} + \text{HCN} \rightarrow \text{CH}_3\text{CH}_2\text{CH}(\text{OH})\text{CN}$

(Total 1 mark)

Q32.

Which one of the following is least likely to occur in the reaction between methane and chlorine?

- A** $\text{CH}_4 + \text{Cl}\cdot \rightarrow \text{CH}_3\cdot + \text{HCl}$
- B** $\text{CH}_3\cdot + \text{HCl} \rightarrow \text{CH}_3\text{Cl} + \text{H}\cdot$
- C** $\text{CH}_3\cdot + \text{Cl}_2 \rightarrow \text{CH}_3\text{Cl} + \text{Cl}\cdot$
- D** $\text{CH}_3\text{Cl} + \text{Cl}\cdot \rightarrow \text{CH}_2\text{Cl}\cdot + \text{HCl}$

(Total 1 mark)

Mark schemes

Q1.



Ignore state symbols

Allow multiples

M1

(b) Zeolite OR aluminosilicate

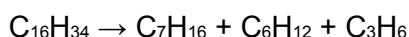
Allow porous pot / aluminium oxide / alumina / silica / silicon dioxide

M1

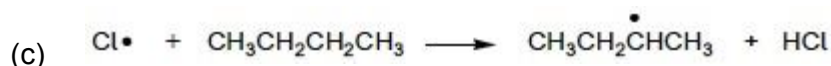
Slight/moderate pressure

Slightly above atmospheric – allow 1-5 atmospheres / 100-500kPa

M2



M3



If incorrect radical or ambiguous radical lose M1 but can award M2 for ecf in each equation.

M1



Allow equations in either order

Allow dot anywhere on the second carbon

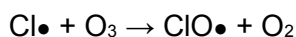
Ignore extra initiation and termination steps

M2

(d) $\text{Cl}\cdot$

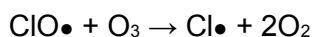
Allow Cl or Chlorine in M1 and M4

M1



Penalise absence of dot once in the equations

M2



Allow dot anywhere on the radical

Apply the list principle in the equations and penalise

M3

$\text{Cl}\cdot$ is regenerated (and causes a chain reaction in the decomposition of ozone)

initiation from Cl_2

Allow equations in either order.

Ignore $\text{Cl}\cdot$ acts as a catalyst

M4

[10]

Q2.
D

[1]

Q3.
D

[1]

Q4.

- (a) (Strength depends on availability of) lone pair on N (atom)

M1

E N (next to ring): (lp) delocalised into ring

M2

(lp) less available (to donate to or to accept a H⁺)

M3

F or **G**: N (next to alkyl): (positive) inductive effect/electrons pushed to N

M4

(lp) more available (to donate to or to accept a H⁺)

M5

order of increasing base strength **E<G<F**

*Or **F** is most basic **and E** is least basic*

M6

- (b) Intermediate compounds

Product of step 1 C₆H₅CH₂Cl

Allow C₆H₅CH₂Br

Product of step 2 C₆H₅CH₂CN

In steps 2 and 3, only allow marks for reagents/conditions if intermediate compounds are correct or close.

Reagents/conditions

Step 1

Cl₂ & UV

Allow Br₂ & UV

Step 2

KCN alcoholic & aq (both reqd)

Ignore temperature

Step 3

H₂ / Ni or Pt or Pd

Allow LiAlH₄ in (dry) ether – (with acid CE, followed by acid allow)

Not NaBH₄ and not Sn/HCl or Fe/HCl

Q5.

A

[1]

Q6.

C

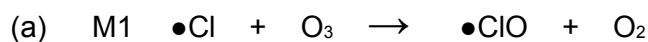
[1]

Q7.

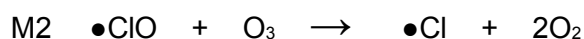
C

[1]

Q8.



1



1

M1 and M2 could be in either order

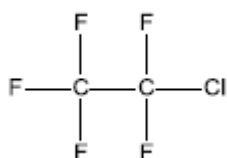
Credit the dot anywhere on the radical

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



Must be displayed formula

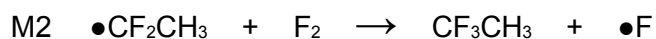
1

- (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



1



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 $\text{CF}_3\text{CH}_3 = 1410/84(.0)$ (=16.8, 16.79 mol)

1

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

1

Correct answer scores both marks

Allow M2 for $M1 \times \text{Avogadro}$ 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]

Q9.

- (a) (i) $\text{CH}_3\text{Cl} + 2\text{Cl}_2 \rightarrow \text{CHCl}_3 + 2\text{HCl}$

IGNORE state symbols

ALLOW multiples

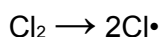
1

- (ii) (Free-)radical substitution

This answer only

1

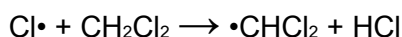
- (iii) Initiation:



Penalise absence of dot once only

1

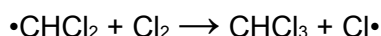
1st Propagation step



Penalise + and/or – charges every time

1

2nd Propagation step

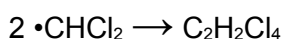


ALLOW $\cdot$ anywhere on $\cdot\text{CHCl}_2$ but, if drawn out as a structure, then

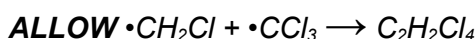
$\cdot$ must be on C

1

Termination



Mark independently

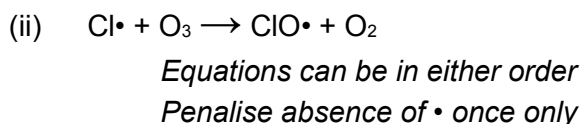


IGNORE state symbols throughout

1

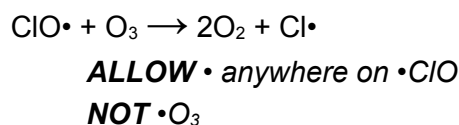
- (b) (i) $\text{CClF}_3 \rightarrow \cdot\text{CF}_3 + \text{Cl}\cdot$

ALLOW $\cdot$ anywhere on $\cdot\text{CF}_3$ unless displayed



1

1

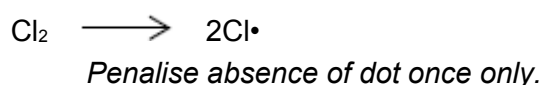


1

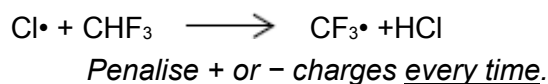
[9]

Q10.

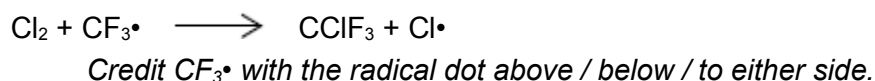
(a) (i) **M1 Initiation**



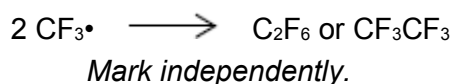
M2 First propagation



M3 Second propagation



M4 Termination (must make C_2F_6)



4

(ii) ultra-violet / uv / sun light

OR (very) high temperature

OR $500^\circ\text{C} \leq T \leq 1000^\circ\text{C}$

OR $773\text{ K} \leq T \leq 1273\text{ K}$

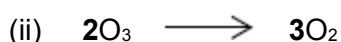
1

(b) (i) $\text{Cl}\cdot$ **OR** chlorine atom / chlorine (free-) radical / Cl (atom)

Not 'chlorine' alone.

Credit 'Cl' alone on this occasion.

1



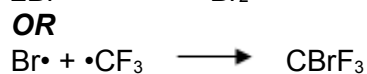
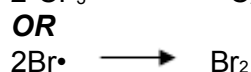
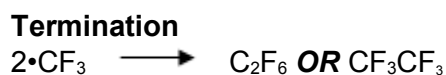
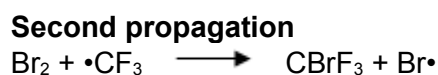
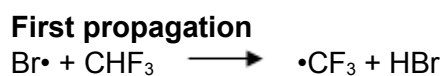
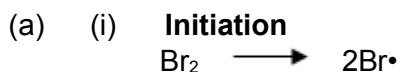
Or multiples.

Ignore state symbols.

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

1

Q11.



Penalise absence of dot once only

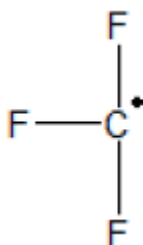
Credit the dot anywhere on the radical

4

- (ii) Ultra-violet / uv / sunlight
OR
 $T > 100^\circ\text{C}$ 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)

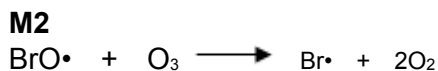
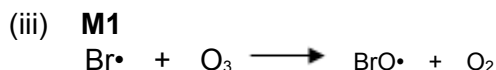
Requires a comparison between the two bonds

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



***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

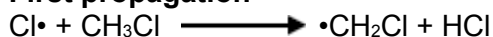
[10]

Q12.



Penalise absence of dot once only.

First propagation

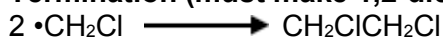


Credit the dot anywhere on the radical.

Second propagation



Termination (must make 1,2-dichloroethane)

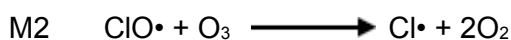
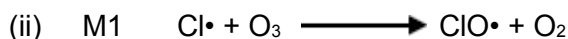


Penalise $\text{C}_2\text{H}_4\text{Cl}_2$

4

- (b) (i) (chlorine free) radical
Ignore formula.

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.

2

[7]

Q13.

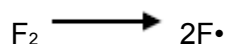
- (a) (i) (Free-) radical substitution

Both underlined words are required

Penalise a correct answer if contradicted by an additional answer

1

- (ii) **Initiation**



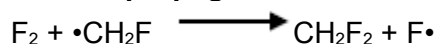
Penalise absence of dot once only

First propagation



Penalise + or - charges every time

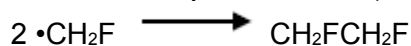
Second propagation



Accept dot anywhere on CH₂F radical

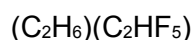
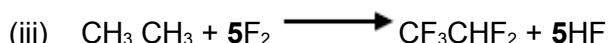
Mark independently

Termination (must make 1,2-difluoroethane)



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

4



1

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

Accept phonetic spelling eg "fluro, cloro"

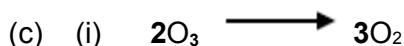
Penalise "flouro" and "floro", since QoL

OR

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

Ignore commas and hyphens

1

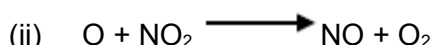


ONLY this equation or a multiple

Ignore NO over the arrow

Other species must be cancelled

1



ONLY this answer and NOT multiples

Ignore any radical dot on the O atom

1

[9]

Q14.

- (a) (i) **M1 Initiation**
 $\text{Cl}_2 \longrightarrow 2\text{Cl}\cdot$
Penalise absence of dot once only.
Penalise + or – charges every time
- M2 First propagation**
 $\text{Cl}\cdot + \text{CH}_2\text{Cl}_2 \longrightarrow \cdot\text{CHCl}_2 + \text{HCl}$
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**
 $\text{Cl}_2 + \cdot\text{CHCl}_2 \longrightarrow \text{CHCl}_3 + \text{Cl}\cdot$
Penalise once only for double headed curly arrows
Mark independently
- 3
- (ii) **M1 Condition**
 ultra-violet / uv / sun light
- OR** high temperature
- OR** $400^\circ\text{C} \leq T \leq 900^\circ\text{C}$
- M2 Type of mechanism**
 (free-) radical substitution (mechanism)
- 2
- (b) (i) $\text{CHCl}_3 + \text{Cl}_2 \longrightarrow \text{CCl}_4 + \text{HCl}$
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 $\text{Cl}\cdot$**
C–Cl / carbon-chlorine bond breakage occurs
OR $\text{Cl}\cdot$ / chlorine (free) radical forms
OR correct equation $\text{CHClF}_2 \longrightarrow \text{Cl}\cdot + \cdot\text{CHF}_2$

Penalise **M1**, if $\text{Cl}\cdot$ 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 $\text{Cl}\cdot$ formation or $\text{C}-\text{Cl}$ / carbon-chlorine bond breakage



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; $2\text{O}_3 \longrightarrow 3\text{O}_2$

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

$\text{Cl}\cdot$ catalyses the decomposition of ozone / a single $\text{Cl}\cdot$ 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) / $\text{C}-\text{Cl}$ (bonds)
Ignore "chlorine molecules"

OR

It does not produce $\text{Cl}\cdot$ / does not produce chlorine (free) radical(s)

OR

chlorodifluoromethane does contain chlorine / does produce $\text{Cl}\cdot$ / does produce chlorine (free) radical(s)

OR

$\text{C}-\text{F}$ is too strong and does not break / create radicals

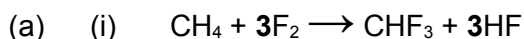
OR

$\text{C}-\text{F}$ is stronger than $\text{C}-\text{Cl}$

1

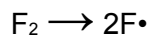
[14]

Q15.

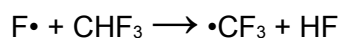


1

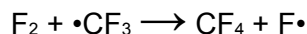
(ii) **M1 Initiation**



M2 First propagation



M3 Second propagation



M4 Termination (must make C₂F₆)



Penalise absence of dot once only.

Radical dot on $\cdot\text{CF}_3$ can be anywhere but if the structure is drawn out, the dot must be on the carbon atom. Penalise this error once only.

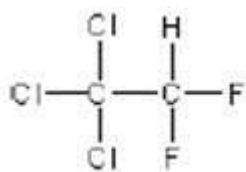
Penalise once only for a line and two dots to show a bond.

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

4

(b) (i) Displayed formula

e.g.



All bonds 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 $2\text{O}_3 \longrightarrow 3\text{O}_2$

M1 NOT carbon-halogen

Penalise incorrect spelling of chlorine once only in this clip

M2 ignore formulae

Ignore Cl₂ or Cl• or ClO• balanced on both sides of the equation

Ignore other equations leading to the overall equation

3

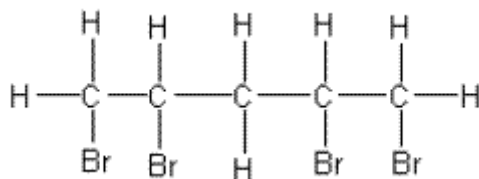
[9]

Q16.

- (a) (i) (Free-) radical substitution
Both words needed
1
- (ii) UV light/Ultra-violet light/sunlight
OR high temperature/ $150\text{ }^{\circ}\text{C} \leq T \leq 500\text{ }^{\circ}\text{C}$
1
- (iii) Propagation (Step)
Ignore "first" or "second"
Accept phonetic spelling
1
- (iv) **M1** Termination (Step)
M2 $2\text{CH}_3\text{CH}_2\text{CH}_2\cdot \longrightarrow \text{C}_6\text{H}_{14}$
In M2
 C_6H_{14} may be drawn out as $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_3$
The dot may be anywhere around the terminal CH_2 on the radical
Accept $\text{C}_3\text{H}_7\cdot$ with dot anywhere
Penalise the absence of any radical dot
2
- (v) $\text{C}_3\text{H}_8 + 8\text{Br}_2 \longrightarrow \text{C}_3\text{Br}_8 + 8\text{HBr}$
Or multiples
1
- (b) (i) **M1** Double bonds are
electron-rich
OR electron pair donors
OR centres of electron density.
M2 Bromine becomes polarised/becomes polar
OR forms an induced dipole
OR becomes δ^+/δ^-
M1 QoL – require one 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 solely as a consequence of electronegativity
2
- (ii) Electrophilic addition
Both words needed
Accept phonetic spelling
1
- (iii) Structure for 1,2,4,5-tetrabromopentane, for example



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]

Q17.

(a) (i) chlorotrifluoromethane

Spelling must be correct but do not penalise "flouro"

Ignore use of 1-

1

(ii) $\text{CF}_3\cdot$

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"

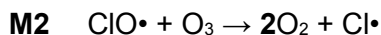
NOT "pair of electrons"

NOT "electrons"

Ignore "(free) radical"

1

(b) **M1** $\text{Cl}\cdot + \text{O}_3 \rightarrow \text{ClO}\cdot + \text{O}_2$



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 C₅H₁₂"

1

[9]

Q18.

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

Both words needed

1

M2 $\text{Cl}_2 \rightarrow 2\text{Cl}\cdot$

1

M3 $\text{Cl}\cdot + \text{CH}_4 \rightarrow \cdot\text{CH}_3 + \text{HCl}$

1

M4 $\text{Cl}_2 + \cdot\text{CH}_3 \rightarrow \text{CH}_3\text{Cl} + \text{Cl}\cdot$

1

M5 $\text{CH}_4 + 3\text{Cl}_2 \rightarrow \text{CHCl}_3 + 3\text{HCl}$

Penalise the absence of a radical dot once only

Ignore termination steps except, if and only if both M3 and M4 do not score, then accept for one mark

$\text{Cl}\cdot + \cdot\text{CH}_3 \rightarrow \text{CH}_3\text{Cl}$

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 Cl₂, but credit UV and C–Cl bond breakage if seen

1

M3 $\text{Cl}\cdot + \text{O}_3 \rightarrow \text{ClO}\cdot + \text{O}_2$

1

M4 $\text{ClO}\cdot + \text{O}_3 \rightarrow \text{Cl}\cdot + 2\text{O}_2$

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 $2\text{O}_3 \rightarrow 3\text{O}_2$
- 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 $\text{Cl}\cdot$ on both sides of the equation

- M6** Stated that the role of the $\text{Cl}\cdot$ / chlorine atom is to find an alternative route **OR** lower E_a / activation energy

1

- (c) **M1** Halothane contains $\text{C}-\text{Cl}$ / Cl
OR
Desflurane does not contain $\text{C}-\text{Cl}$ bonds / Cl
OR
Desflurane contains $\text{C}-\text{F}$ / F as the only halogen

Mark independently.

For M1, credit the idea that desflurane contains $\text{C}-\text{F}$ bonds that are difficult to break OR that halothane contains $\text{C}-\text{Cl}$ 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]

Q19.

- (a) Functional group (isomerism)

1

- (b)

M1 Tollens' (reagent)
(Credit ammoniacal silver nitrate
OR a description of making
Tollens')
(Ignore either AgNO_3 or $[\text{Ag}(\text{NH}_3)_2]^+$
or "the silver mirror test" on their
own, but mark M2 and M3)

M2 silver mirror

OR

black solid/precipitate
(NOT silver precipitate)

M3 (stays) colourless
or no change or no reaction

M1 Fehling's (solution) or
Benedict's solution
(Ignore $\text{Cu}^{2+}(\text{aq})$ or
 CuSO_4 on their own, but mark
on to M2 and M3)

M2 Red solid/precipitate
(Credit orange or brown solid)

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)

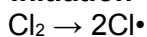
1

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

Penalise "(free) radical mechanism"

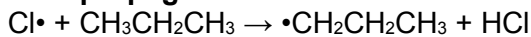
1

- (ii) **Initiation**



Penalise absence of dot once only.

First propagation

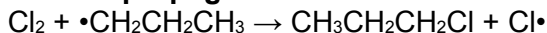


OR C_3H_8

Penalise incorrect position of dot on propyl radical once only.

Penalise $\text{C}_3\text{H}_7\cdot$ once only

Second propagation

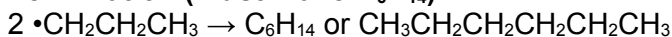


OR



Accept $\text{CH}_3\text{CH}_2\text{CH}_2\cdot$ with the radical dot above/below/to the side of the last carbon.

Termination (must make C_6H_{14})



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]

Q20.

- (a) (i) (free-)radical substitution
(both words required for the mark) 1
- (ii) uv light OR sunlight OR high temperature OR 150 °C to 500 °C 1
- (iii) Propagation
(ignore "chain", "first", "second" in front of the word propagation) 1
- (iv) Termination 1
- $\bullet\text{CH}_2\text{CH}_3 + \text{Br}\bullet \longrightarrow \text{CH}_3\text{CH}_2\text{Br}$
OR $2\bullet\text{CH}_2\text{CH}_3 \longrightarrow \text{C}_4\text{H}_{10}$
(penalise if radical dot is obviously on CH_3 , but not otherwise)
(penalise $\text{C}_2\text{H}_5\bullet$)
(credit $2\text{Br}\bullet \longrightarrow \text{Br}_2$)
(ignore "chain" in front of the word termination) 1
- (b) (i) Fractional distillation OR fractionation
(credit gas-liquid chromatography, GLC) 1
- (ii) $\text{CH}_3\text{CH}_3 + 6\text{Br}_2 \longrightarrow \text{C}_2\text{Br}_6 + 6\text{HBr}$
(credit C_2H_6 for ethane) 1
- (c) Correct structure for $\text{CF}_2\text{BrCF}_2\text{Br}$ drawn out
(penalise "Fl" for fluorine) 1
- (d) (i) 2-bromo-2-chloro-1,1,1-trifluoroethane
OR 1-bromo-1-chloro-2,2,2-trifluoroethane
(insist on all numbers, but do not penalise failure to use alphabet)
(accept "flourine" and "cloro" in this instance) 1
- (ii) 197.4 only
(ignore units) 1
- (iii) $(57/197.4 \times 100) = 28.9\%$ OR 28.88%
(credit the correct answer independently in part (d)(iii), even if (d)(ii) is blank or incorrectly calculated, but mark consequential on part (d)(ii), if part (d)(ii) is incorrectly calculated, accepting answers to 3sf or 4sf only)

(penalise 29% if it appears alone, but not if it follows a correct answer)
 (do not insist on the % sign being given)
 (the percentage sign is not essential here, but penalise the use of units e.g. grams)

1

[11]

Q21.

- (a) (i) (free-) radical substitution

(both words required for the mark)

1

initiation $\text{Cl}_2 \rightarrow 2\text{Cl}\cdot$

(credit correct half arrows, but penalise double headed arrows)

1

first propagation $\text{CH}_3\text{Cl} + \text{Cl}\cdot \rightarrow \cdot\text{CH}_2\text{Cl} + \text{HCl}$

1

second propagation $\cdot\text{CH}_2\text{Cl} + \text{Cl}_2 \rightarrow \text{CH}_2\text{Cl}_2 + \text{Cl}\cdot$

(penalise the absence of dots on radicals once only)

(penalise radical dot on Cl of CH_2Cl once only)

1

- (ii) $\text{CH}_3\text{Cl} + \text{Cl}_2 \rightarrow \text{CH}_2\text{Cl}_2 + \text{HCl}$

(penalise if any radicals appear in this equation)

1

- (b) **M1:** mol C = $10.1/12.0$ and mol Cl = $89.9/35.5$

1

M2: Ratio 0.842 : 2.53 OR 1: 3 OR CCl_3

1

M3: $237.0/\text{Mr of } \text{CCl}_3 = 237.0/118.5 = 2$ Therefore C_2Cl_6

(correct answer gains full credit)

1

OR

M1: $237.0 \times 10.1/100$ and $237 \times 89.9/100$

1

M2: Ratio $23.9/12.0 : 213/35.5$ OR 2 : 6

1

M3: C_2Cl_6

(correct answer gains full credit)

1

- (c) any two from CHBr_3 or CBr_4 or $\text{C}_2\text{H}_2\text{Br}_4$ (or $\text{CHBr}_2\text{CHBr}_2$) or C_2Br_6 (or CBr_3CBr_3)

(ignore HBr or H_2)

(ignore equations and ignore names when given in addition to formulae)

(penalise names alone)

Q22.

M1: uv light/sunlight

OR

T = 450 °C to 1000 °C;

*(do not credit "high temperature")**(ignore references to pressure or catalyst)**(penalise M1 if aqueous chlorine OR chlorine water)**(credit M1 if the condition appears over the arrow of the initiation step)*

1

M2: $\text{Cl}_2 \rightarrow 2\text{Cl}\cdot$;*(credit correct half arrows, but penalise (once in the question) the use of double headed arrows)*

1

M3: $\text{C}_2\text{H}_6 + \text{Cl}\cdot \rightarrow \text{CH}_3\text{CH}_2\cdot + \text{HCl}$;*(credit CH_3CH_3 for ethane and $\text{C}_2\text{H}_5\cdot$ for the ethyl radical)*

1

M4: $\text{CH}_3\text{CH}_2\cdot + \text{Cl}_2 \rightarrow \text{C}_2\text{H}_5\text{Cl} + \text{Cl}\cdot$;

1

M5: $\text{CH}_3\text{CH}_2\cdot + \text{CH}_3\text{CH}_2\cdot \rightarrow \text{C}_4\text{H}_{10}$;*(penalise the absence of dots once only in this question)**(penalise subsequent ionic reactions as contradictions for each reaction contradicted)**(if neither M3 nor M4 scored, allow $\text{CH}_3\text{CH}_2\cdot + \text{Cl}\cdot \rightarrow \text{C}_2\text{H}_5\text{Cl}$ for one mark)*

1

[5]

Q23.(a) $\text{F}_2 \rightarrow 2\text{F}\cdot$

1

 $\text{CH}_4 + \text{F}\cdot \rightarrow \cdot\text{CH}_3 + \text{HF}$

1

 $\cdot\text{CH}_3 + \text{F}_2 \rightarrow \text{CH}_3\text{F} + \text{F}\cdot$

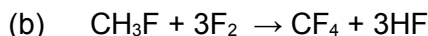
1

 $\cdot\text{CH}_3 + \text{F}\cdot \rightarrow \text{CH}_3\text{F}$

1

OR $2\cdot\text{CH}_3 \rightarrow \text{C}_2\text{H}_6$ *(allow credit on this occasion for $2\text{F}\cdot \rightarrow \text{F}_2$)*

(penalise incorrect symbol FI, once only)
(penalise absence of radical dot once only)



1

[5]

Q24.

- (a) (i) (Free) radical substitution
(Both words needed)

1

- (ii) M1 initiation ONLY

1

M2 ultra-violet light OR sunlight OR $1000^\circ\text{C} \geq T \geq 450^\circ\text{C}$
(Ignore reference to temperature if included with uv light)
(Penalise "high temperature" for M2)

1

- (iii) $2\dot{\text{C}}\text{H}_3 \rightarrow \text{C}_2\text{H}_6$
(OR CH_3CH_3 as alternative to C_2H_6)

1

- (iv) $\text{CH}_3\text{Br} + \text{Br}_2 \rightarrow \text{CH}_2\text{Br}_2 + \text{HBr}$

1

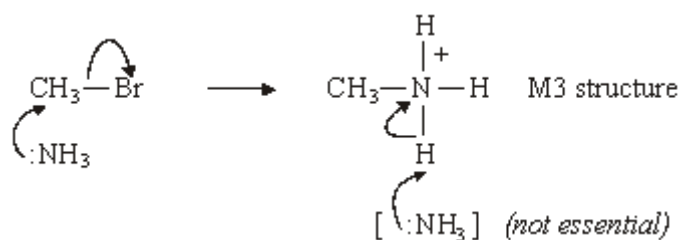
- (b) (i) Electron pair donor
OR species with an electron pair able to form a covalent bond.

1

- (ii) Methylamine
(Credit "aminomethane")

1

- (iii)



1

M1 arrow to show breakage of C – Br bond

1

M2 arrow from lone pair on N of NH_3 to form bond with C

1

M4 arrow from bond of N – H to N atom of CH_3NH_3^+
(Ignore partial charges on haloalkane but penalise if incorrect)

(Accept $\text{CH}_3\overset{+}{\text{N}}\text{H}_3$ for M3)

(Full credit for carbocation mechanism; M1 for C – Br bond breakage and M2 for lone pair attack on carbocation)

(Second mole of ammonia not essential to mechanism for full credit)

1

[11]

Q25.

- (a) (i) UV light OR sunlight OR $T \geq 450^\circ\text{C}$ (1)
NOT high T

- (ii) (free) radical substitution (1)

- (iii) CCl_4 (1) OR named

3

- (b) (i) $\text{CH}_3\text{Cl} + \text{KCN} \rightarrow \text{CH}_3\text{CN} + \text{KCl}$ (1)
 $\text{CN}^- \qquad \qquad \text{Cl}^-$

- (ii) nucleophilic substitution (1)

- (iii) C–Br bond is weaker (than C–Cl bond)
OR C–Br bond enthalpy is less than C–Cl (1)
Ignore electronegativity

3

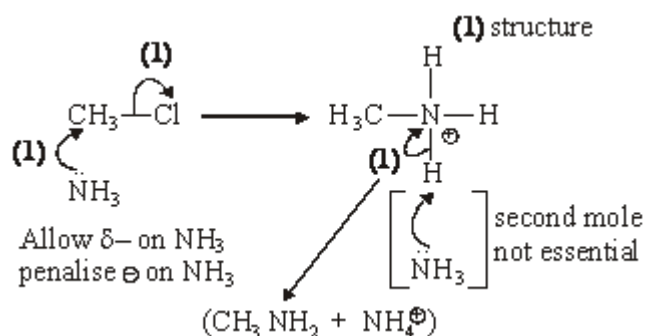
- (c) CH_3COOH OR ethanoic acid (1)

1

- (d) (i) $\overset{\delta+}{\text{C}}-\overset{\delta-}{\text{Cl}}$ OR C–Cl is polar (1) OR C atom is electron deficient / $\delta+$

- (ii) methylamine (1) only

- (iii) $\text{S}_{\text{N}}1$ scores full marks



6

[13]

Q26.

- (a) (i) $\text{CHCl}_3 + \text{Cl}_2 \rightarrow \text{CCl}_4 + \text{HCl}$ (1)

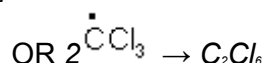
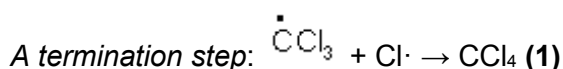
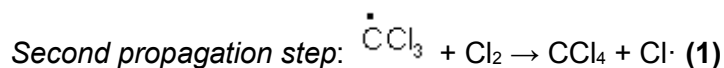
- (ii) UV light / sunlight OR high T OR $T \geq 500^\circ\text{C}$ (1)

$\text{max}T = 1000^{\circ}\text{C}$
 NOT heat / light
 Ignore pressure

2

- (b) Initial step: $\text{Cl}_2 \rightarrow 2\text{Cl}\cdot$ (1)

Condition could be on first equation arrow



Not $2\text{Cl}\cdot \rightarrow \text{Cl}_2$

Ignore additional termination steps

4

[6]

Q27.

C

[1]

Q28.

Penalise missing • once only

- (i) $\text{Cl}_2 \rightarrow 2\text{Cl}\cdot$ (1)

- (ii) $\text{CH}_2\text{Cl}_2 + \text{Cl}_2 \rightarrow \text{CHCl}_3 + \text{HCl}$ (1)

- (iii) $\text{CH}_2\text{Cl}_2 + \text{Cl}\cdot \rightarrow \text{CHCl}_2\cdot + \text{HCl}$ (1)
 $\text{CHCl}_2\cdot + \text{Cl}_2 \rightarrow \text{CHCl}_3 + \text{Cl}\cdot$ (1)

Can reverse order

- (iv) Effect on rate: increases (1) If decrease given C.E zero marks

Explanation: more $\text{Cl}\cdot$ radicals formed (1)

More Cl atoms, more $\text{Cl}-\text{Cl}$ or Cl_2 bonds broken, more Cl_2 have

E_a , increased rate of $\text{Cl}\cdot$ production

[6]

Q29.

- (a) Condition: U.V. light or sunlight or 450°C or high temp (1)

Explanation: U.V. light etc. provides energy to break($\text{Cl}-\text{Cl}$) bond (1)

Do not accept reference to E_a or wrong bond or 'to make $\text{Cl}\cdot$

(b) (i) (Free) radical substitution **(1)**

(ii) *Step 1: initiation (1)*

Step 2: propagation (1)

Step 3: termination (1)

Any order

Don't be too harsh on spelling

4

(c) (i) *Equation 1: $\text{CH}_3 + \text{Cl}\cdot \rightarrow \text{CH}_2\text{Cl}\cdot + \text{HCl}$ (1)*
Equation 2: $\text{CH}_2\text{Cl}\cdot + \text{Cl}_2 \rightarrow \text{CH}_2\text{Cl}_2 + \text{Cl}\cdot$ (1)

or $\text{CH}_2\text{Cl}\cdot + \text{Cl}\cdot \rightarrow \text{CH}_2\text{Cl}_2$

Mark equ independently

any order

(ii) $\text{CH}_2\text{Cl}\cdot + \text{CH}_3\cdot \rightarrow \text{CH}_3\text{CH}_2\text{Cl}$ **(1)**

or $\text{CH}_3\text{CH}_2\cdot + \text{Cl}_2 \rightarrow \text{CH}_3\text{CH}_2\text{Cl} + \text{Cl}\cdot$

or $\text{CH}_3\text{CH}_2\cdot + \text{Cl}\cdot \rightarrow \text{CH}_3\text{CH}_2\text{Cl}$

Equ must have $\text{CH}_3\text{CH}_2\text{Cl}$ as product

Accept $\text{C}_2\text{H}_5\text{Cl}$

Penalise absence of $\cdot$ once only

3

[9]

Q30.

B

[1]

Q31.

D

[1]

Q32.

B

[1]

Examiner reports

Q1.

- (a) The equation was an easy starter and 90.1% of the students gained the mark.
- (b) Most students were able to give a correct catalyst and the correct equation. However, the pressure condition was not answered well. Low or high pressure were common wrong answers and there were some contradictions. Although temperature was not required, it was sometimes given.
- (c) Only the better students scored both marks, but nearly two-thirds of the students scored one out of two. Common errors were to give the ambiguous radical, $C_4H_9\cdot$ or $\cdot C_4H_9$, or to show poor placement of the dot on carbon number 2.
- (d) This four mark question was answered well and 40.2% of candidates gained full marks. The chlorine radical was well known although F and other radicals from the CFC were seen. A few students thought that Cl came from Cl_2 rather than from the CFC and this was penalised. There were a few missing dots in the equations. Mark point 4 was usually gained, although some candidates wrote about Cl acting as a catalyst and not being used up, without stating that it was regenerated/reformed.

Q2.

This was an extremely accessible question (96.7% correct).

Q3.

This was answered well with a high proportion of the students (68.8%) scoring the mark.

Q4.

- (a) The full range of marks was seen and included some excellent answers. Other responses did not contain accurate descriptions of the effect of the attached groups on the availability of the lone pair on the nitrogen atom. The idea that, for nitrogen atoms directly attached to the benzene ring, the lone pair was delocalised into the ring was often poorly explained. The (positive) inductive effect of alkyl groups was much better described.
- (b) Some excellent answers were seen, but overall this was not answered well. The fact that about 8% of students made no attempt at this part of the question perhaps indicated that a small number of students were short of time. Some students, confused by the presence of a benzene ring, started with nitration. This rarely led to any marks. For those who chose the correct route, the two intermediates were often correctly identified. The use of chlorine or bromine in UV in the first step was usually well known but use of the reagent KCN in a mixed aqueous/alcoholic solvent was less often correct in the next step. The expected reducing agent/condition for the final step was hydrogen with a nickel or platinum catalyst. $LiAlH_4$ in dry ether is not required knowledge for this specification, but was an acceptable answer.

Q8.

Free radical reactions

In (a) the two equations showing how chlorine radicals destroy ozone were quite well

known. Many students in (b) could draw the correct displayed formula of chloropentafluoroethane. Many students in (c) could explain why 1,1,1-trifluoroethane did not lead to ozone depletion. The simplest answer was that it contains no chlorine, but credit was given for students who stated that the C-F bonds were strong and so fluorine radicals were not released. Students in (d) found the two propagation steps to convert CHF_2CH_3 into CF_3CH_3 more challenging, but a pleasing number could do this. The most common mistake was to remove a Hydrogen atom from the wrong Carbon atom in the first step. Students found (e) - the calculation for the number of molecules - challenging. Some had little idea where to start while many others failed to convert kg to g and/or give their final answer to the correct number of significant figures. Few students knew (f) that molecules with vibrating polar bonds absorb IR radiation.

Q9.

This question was generally answered well throughout.

The commonest mistakes seen were for the propagation steps in the mechanism where CH_3Cl was used instead of CH_2Cl_2 and for dots to be missing from radicals in parts (b)(i) and (b)(ii).

Q10.

Part (a) required a free-radical substitution mechanism for molecules with two different halogens and it discriminated well. In common with previous questions involving a similar mechanism, the second propagation step proved to be the most demanding part of this question. The remainder of the question was relatively high scoring.

Q11.

This discriminated well with 85% scoring at least two marks in part (a)i and 70% all four marks. In part (b)ii, only 35% were able to draw a correct displayed formula for the trifluoromethyl radical; many answers giving a correct structure but including a positive charge or a lone pairs of electrons on carbon. Many good answers were seen in part (b)ii in which the two carbon-halogen bonds were compared correctly. By contrast part (b)iii proved quite demanding with only 46% gaining all three marks. Errors in the formulas of species and in balancing equations were common, whilst the idea of the bromine atom being regenerated was well understood.

Q12.

The free-radical substitution mechanism always discriminates well and this was no exception. Almost three-quarters of all students scored 2 marks but fewer than 10% scored 4 marks. It was important in the termination step to show clearly that the product is 1,2-dichloroethane.

Some good responses were seen in part (b) perhaps because this is straight from the specification, although only half of all students scored both marks in part (b)(ii).

Q13.

Part (a)(ii) of this question discriminated extremely well, although the termination step caused problems for those who were determined to produce difluoromethane. Phonetic spelling was allowed in part (b), but other incorrect spelling, such as "flouro", was penalised. Students were required to cancel through any additional species on both sides of the equation for credit to be awarded in part (c)(i) and 51% scored this mark. Only one answer was acceptable for the more demanding part (c)(ii) and 18% were successful.

Q14.

Part (a) involved familiar chemistry and despite this, some students struggled to score many marks, making the usual mistakes. Identification of CCl_4 as the unknown **X** was accessed by many in part (b) and equations were generally done well. The explanation of the infrared spectrum usually yielded some credit but only the best students linked together the fact that there is an absorption missing in the range $2850 - 3300 \text{ cm}^{-1}$ with the idea either that CHCl_3 has a C–H bond that would give rise to that absorption or that CCl_4 does not.

In part (c), too many students referred to Cl_2 as the source of chlorine atoms in the upper atmosphere rather than referring to the breakage of the C–Cl bond in CHClF_2 . Most students attempted to write the correct equations for the catalytic decomposition of ozone and understood the significance of this process. Part (d) was generally answered well.

Q15.

Candidates found this question quite demanding, with, for example, only 31% scoring the mark in part (a)(i). In part (a)(ii) candidates sometimes lost marks because they used curly half-arrows incorrectly or they became confused in the propagation steps. Notwithstanding these problems, this mechanism provided a good opportunity for almost all candidates to show what they could do. Part (b)(i) was very high-scoring whereas part (b)(ii) proved a bigger challenge with full marks from only 18% of candidates and 24% scoring no marks.

Q16.

Candidates had little difficulty with all of part (a), although incorrect equations showing hydrogen as a product were seen in part (a)(v). Part (b)(i) required a clear explanation that the electron density of the double bond induced a dipole in the bromine molecule. The remainder of this question was relatively high scoring.

Q17.

This question was not as high scoring as might have been expected. Candidates were unfamiliar with the equations that show how chlorine atoms catalyse the decomposition of ozone, even though these are in the specification. The ability to articulate a correct argument using Le Chatelier's principle in part (c)(ii) was well done, although candidates should be urged to refer to the "equilibrium" rather than the "system".

Q18.

The stem of this question was about the development of compounds used as anaesthetics. Part (a) was an example of free-radical substitution. Candidates have difficulty with this mechanism beyond its name and the initiation step and this proved to be the case here with only 45% of the candidates gaining more than two marks. Part 10(b) was chemistry new to this unit. The question was about the probable impact of chlorine-containing compounds on the ozone layer in the upper atmosphere. Only a minority scored all 6 marks, with only 45% able to score at least 2 marks. Rather too many candidates made imprecise statements or did not know the content of the Specification sufficiently well to allow them to access this question. Part (c) required an appreciation of the difference, in terms of bonds and atoms present, between *desflurane* and *halothane*. Almost 75% of the candidates were able to gain at least half of the marks.

Q19.

Recognising functional group isomerism in part (a) proved difficult for many candidates whereas testing for an aldehyde was generally done well in part (b). The free-radical

substitution in part (d) produced a wide range of marks and only the best candidates scored full marks. The use of precise M_r values in part (e) was new and only 38% scored any marks.

Q20.

This was a high scoring question with many scores of eight or more marks. In part (a) candidates were penalised if the radical dot was shown to be on the CH_3 group, rather than as given in the question. In part (b) many equations gave hydrogen as the product rather than hydrogen bromide, suggesting that candidates had difficulty applying the information to a novel situation. Parts (c) and (d) (i) were frequently correct, although the failure to number all of the substituents on the two carbon atoms of haloethane was penalised. In part (d) (ii), many candidates had problems using the data to calculate a correct relative molecular mass and the answer of 197.4 was the only response accepted. In part (d) (iii), consequential credit was awarded, with correct answers to either 3 or 4 significant figures being accepted.

Q21.

This question usually yielded at least half marks for most candidates. In part (a), the word "substitution" was occasionally omitted. Weaker candidates struggled to present correct propagation steps, but could complete both the initiation step and the overall equation. Centres should encourage candidates to place the unpaired electron on a carbon atom when writing the formula for a free-radical intermediate.

Part (b) caused few problems for many candidates, although several could get no further than a correct empirical formula and then manipulated the numbers to produce an incorrect molecular formula.

In part (c) most candidates could get CHBr_3 , but a second formula proved elusive for some, with HBr a common incorrect answer.

Q22.

This was probably the best answered question on the paper, with many candidates scoring at least three out of the five marks and many scoring full marks. The mark missed most frequently was the second propagation step. Candidates should be advised strongly not to write curly arrows in radical substitution reactions, because too many mistakes are made, even when they try (correctly) to use half-headed arrows. They should also be advised that they will lose credit if they write a correct mechanism and then contradict this mechanism with one which includes ionic species.

Q23.

This was the first occasion that fluorine had been used in a question of this type and it was good to see that the majority of candidates were able to apply their knowledge and score at least three of the five marks. The symbol "F" was penalised once only and the improbable recombination of two fluorine atoms into a fluorine molecule was given credit as a termination step, since it represented logical thinking by the candidate. The most difficult part of the question proved to be part (b) and unbalanced equations or equations with hydrogen or haloalkanes other than tetrafluoromethane were common.

Q24.

Part (a) of this question was well answered by many candidates, with due credit given to those who chose to include half arrows in part (a)(iii); this is not necessary, but is correct

chemistry and will receive credit. The most common error in part (a)(i) was to fail to include the word “substitution” and too often in part (a)(iv) errors were encountered due to incorrectly balanced equations, incorrect products or the use of an incorrect formula. The idea of an electron pair donor and a correct name for methylamine was known by a large number of candidates in parts (b)(i) and (ii). Most candidates had a go at part (b)(iii), sometimes scoring only the mark for the C-Br bond breakage. Even some of the best candidates incorrectly included a negative charge on the ammonia molecule.

Q25.

This question was well answered by many candidates, although in part (a)(ii) the word “substitution” was often missed and weaker candidates had problems recognising that tetrachloromethane would form as the main product when a large excess of chlorine is used. In part (b)(i) marks were lost through equations not being balanced or through errors in the formula of ethanenitrile. In part (b)(iii) the idea from the specification that the “carbon-halogen bond enthalpy influences the rate of hydrolysis” was known and applied in this context by many candidates. Rather too many answers lacked precision and stated simply that “bromomethane has weaker bonds” without indicating the relative strengths of the C-Br and C-Cl bonds. Part (c) was generally answered correctly. In part (d)(i) the demand was for the candidates to appreciate the polar nature of the C-Cl bond, rather than the more vague response that “chloromethane is polar”. In (d)(ii), many candidates were able to name methylamine correctly and attempts at the mechanism in (d)(iii) were generally good. The main problems with many mechanisms arose from the inclusion either of a negative charge on the ammonia molecule or curly arrows going the wrong way on the methylammonium ion, which often lacked a positive charge. Notwithstanding these difficulties most candidates scored at least two marks.

Q26.

Many candidates found parts (a) and (b) difficult. It was obvious from their answers that the conversion from methane to chloromethane had been learned, but the application of this idea to trichloromethane proved difficult. Even when candidates were able to start with a correct formula for trichloromethane, equations were confused, typically with radicals appearing in the overall equation and incorrect products and intermediates throughout both of parts (a) and (b).

Q28.

Parts (i) and (ii) were generally well answered, although equations in (i) showing the reaction of chlorine with substances such as methane, and equations in (ii) which contained such species as Cl^- , HCl , Cl_2 and H_2 , were not uncommon. There were rather more errors in (iii), where equations showing the mono-chlorination of methane, or which contained such species as CH_2Cl_3 , $\text{CH}_2\text{Cl}^\cdot$ and $\text{CH}_2\text{Cl}_2^\cdot$ were quite common. It was not uncommon to see an equation for a termination step offered as the second propagation step. Almost all candidates predicted an increase in rate in (iv), however, the explanations offered frequently lacked precision. Many vague references were seen to increased numbers of radicals, radicals being formed faster, there being more kinetic energy available or that the activation energy being altered by the more intense light. The better candidates correctly attributed the change in rate to an increased rate of production/concentration of chlorine radicals.

Q29.

Part (a) was generally well answered, with most candidates quoting ultraviolet light as the required condition. References to high temperature or sunlight were less common but earned credit, whereas vague references to light or to heat were not accepted. In many

cases, acceptable explanations in terms of the need to break the Cl-Cl bond were given but inaccurate explanations in terms of the activation energy of the reaction, C-H bond cleavage, or of heterolytic fission of the Cl-Cl bond were seen. Part (b) was also generally well done, however, some candidates quoted the mechanism as being 'free radical' but omitted to specify 'substitution'. A few references to 'nucleophilic' or 'electrophilic' mechanisms were also seen. The names quote in part (b)(ii) were almost always acceptable, however, there were some odd misspellings of some of the steps. A few candidates gave incorrect responses, such as 'substitution' or 'reduction'. Although the better candidates coped well with part (c), the overall level of success was lower than that in the earlier parts of the question. In (c)(i), it was not uncommon to see equations omitting CH_3Cl as a reactant or CH_2Cl_2 as a product. Also, it was not unusual for the dots to be omitted from the formulae of radicals, for equations to show species carrying charges or for species such as $\text{HCl}\cdot$ or $\text{CH}_3\text{Cl}\cdot$ to be shown. A termination equation showing the formation of CH_2Cl_2 was accepted for Equation 2. Most candidates gave an acceptable equation to represent the formation, either by termination or as part of a propagation step, of $\text{CH}_3\text{CH}_2\text{Cl}$.