Q1. (a) The equation below shows the reaction of 2-bromopropane with an excess of ammonia.

$$CH_3CHBrCH_3 + 2NH_3 \rightarrow CH_3CH(NH_2)CH_3 + NH_4Br$$

Name and outline the mechanism involved.

Name of mechanism ….....

Mechanism

(5)

(b) When 2-bromopropane is heated with ethanolic potassium hydroxide, an elimination reaction occurs. State the role of potassium hydroxide and outline a mechanism for this reaction.

Role of potassium hydroxide .....

Mechanism

(5)
(Total 10 marks)

Q2. The equation below represents a reaction between methane and chlorine.

$$CH_4(g) + Cl_2(g) \rightarrow CH_3Cl(g) + HCl(g)$$

(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 CH_3CH_2Cl 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 CH_3CH_2Cl is formed.

.....

(3)
(Total 9 marks)

Q3. Reaction of 2-bromobutane with potassium hydroxide can produce two types of product depending on the solvent used. In aqueous solution, the formation of an alcohol, **E**, is more likely but in ethanolic solution the formation of alkenes is more likely.

(a) For each type of product, name the type of reaction occurring and state the role of the potassium hydroxide.

(4)

(b) Name alcohol **E** and draw its structural formula. By reference to the structure of the halogenoalkane, explain why the initial step in the mechanism of the reaction producing the alcohol occurs.

(5)

(c) When 2-bromobutane reacts with ethanolic potassium hydroxide, two structurally isomeric alkenes are produced, one of which shows stereoisomerism.

Outline the mechanism for the formation of one of the structurally isomeric alkenes. Explain why two structurally isomeric alkenes are formed and draw the structure of the second structural isomer. Draw the structural formulae of the two stereoisomers.

(8)
(Total 17 marks)

Q4. 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.

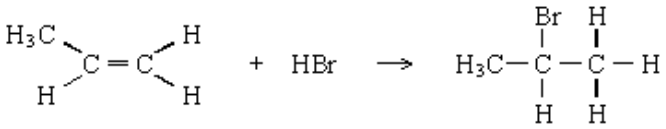
Effect on rate .....

Explanation .....

(Total 6 marks)

Q5. (a) Propene reacts with hydrogen bromide by an electrophilic addition mechanism forming 2-bromopropane as the major product.

The equation for this reaction is shown below.



(i) Outline the mechanism for this reaction, showing the structure of the intermediate carbocation formed.

(ii) Give the structure of the alternative carbocation which could be formed in the reaction between propene and hydrogen bromide.

(5)

(b) A substitution reaction occurs when 2-bromopropane reacts with aqueous sodium hydroxide.

(i) Draw the structure of the organic product of this reaction and give its name.

Structure

Name .....

(ii) Name and outline the mechanism for this reaction.

Name of mechanism .....

Mechanism

(5)

(c) Under different conditions, 2-bromopropane reacts with sodium hydroxide to produce propene.

(i) Name the mechanism for this reaction.

.....

(ii) State the role of sodium hydroxide in this reaction.

.....

(2)
(Total 12 marks)

Q6. (a) Compounds with double bonds between carbon atoms can exhibit geometrical isomerism.

(i) Draw structures for the two geometrical isomers of 1,2-dichloroethene.

Isomer 1 *Isomer 2*

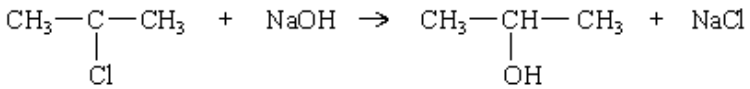
(ii) What feature of the double bond prevents isomer 1 from changing into isomer 2?

.....

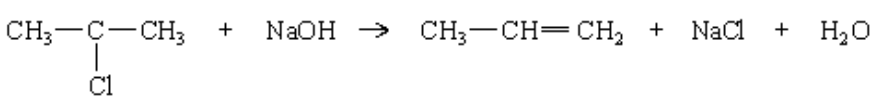
(3)

(b) When 2-chloropropane reacts with sodium hydroxide, two different reactions occur. Each reaction produces a different organic product.

Reaction 1



Reaction 2



(i) Outline a mechanism for **Reaction 1** and state the role of the hydroxide ion in this reaction.

Mechanism

Role of the hydroxide ion .....

(ii) Outline a mechanism for **Reaction 2** and state the role of the hydroxide ion in this reaction.

Mechanism

Role of the hydroxide ion .....

(7)
(Total 10 marks)

Q7. 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

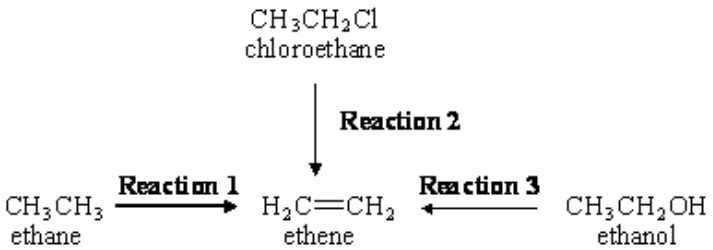
.....

A termination step

.....

(4)
(Total 6 marks)

Q8. Ethene is an important starting point for the manufacture of plastics and pharmaceutical chemicals. Most of the ethene used by industry is produced by the thermal cracking of ethane obtained from North Sea gas (**Reaction 1**). It is also possible to make ethene either from chloroethane (**Reaction 2**) or from ethanol (**Reaction 3**).



(a) Give essential conditions and reagents for each of **Reactions 2** and **3**.

(4)

(b) Name and outline a mechanism for **Reaction 2**. Suggest a reason why chloroethane is **not** chosen by industry as a starting material to make ethene commercially.

(5)

(c) Name and outline a mechanism for **Reaction 3**. Suggest why this route to ethene may become used more commonly in the future as supplies of North Sea gas begin to run out.

(6)

(Total 15 marks)

Q9. (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)

Q10. (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.

$CH_3Br + 2NH_3 \rightarrow CH_3NH_2 + NH_4Br$

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

.....

.....

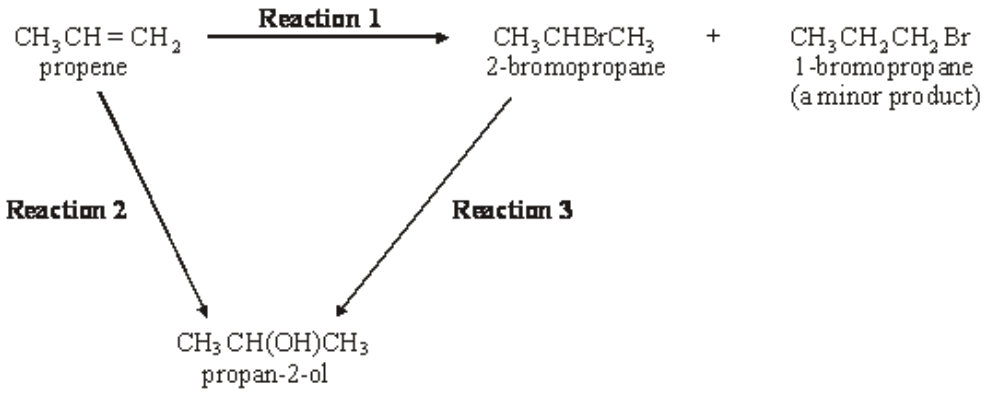
(ii) Name the organic product of this reaction.

.....

(iii) Outline a mechanism for this reaction.

(6)
(Total 11 marks)

Q11. Consider the following reaction scheme.



(a) (i) Name the mechanism for **Reaction 1**.

.....

(ii) Explain why 1-bromopropane is only a minor product in **Reaction 1**.

.....

.....

.....

(3)

(b) Give a suitable reagent and state the essential conditions required for **Reaction 3**.

Reagent .....

Conditions .....

(2)

(c) The reagent used for **Reaction 3** can also be used to convert 2-bromopropane into propene. State the different conditions needed for this reaction.

.....

(1)

(d) **Reaction 2** proceeds in two stages.

Stage 1 $CH_3CH{=}CH_2 + H_2SO_4 \rightarrow CH_3CH(OSO_2OH)CH_3$

Stage 2 $CH_3CH(OSO_2OH)CH_3 + H_2O \rightarrow CH_3CH(OH)CH_3 + H_2SO_4$

(i) Name the class of alcohols to which propan-2-ol belongs.

.....

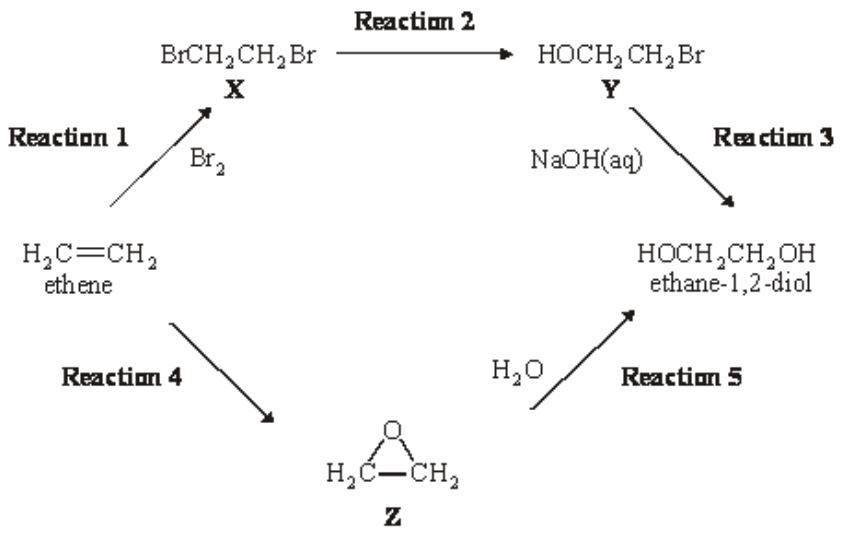
(ii) Outline a mechanism for Stage 1 of **Reaction 2**, using concentrated sulphuric acid.

(iii) State the overall role of the sulphuric acid in **Reaction 2**.

.....

(6)
(Total 12 marks)

Q12. Consider the following scheme of reactions for making ethane-1,2-diol from ethene by two different routes.



(a) Name compound **X** and name a mechanism for **Reaction 1**. Explain why ethene is able to react with bromine in this reaction, given that bromine molecules are non-polar.

(4)

(b) Name and outline a mechanism for **Reaction 3**. Explain why compound **Y** is susceptible to attack by hydroxide ions.

(4)

(c) Identify a reagent and a suitable catalyst for **Reaction 4**. Name compound **Z** and explain why compound **Z** reacts readily with water in **Reaction 5**.

(4)

(d) Give a use for ethane-1,2-diol. For **each** route from ethene to ethane-1,2-diol, identify **one** hazard.

(3)

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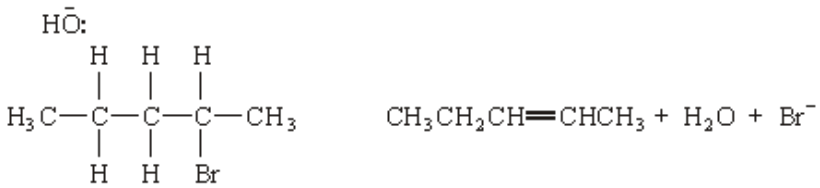
(Total 15 marks)

Q13. (a) Complete the mechanism below by drawing appropriate curly arrows.



2-bromopentane pent-2-ene

(3)

(b) Draw and name the geometrical isomers of pent-2-ene.

Isomer 1 *Isomer 2*

Name .....…..... *Name* .....…..... **(2)**

(c) Pent-1-ene reacts with hydrogen bromide to produce 2-bromopentane as the major product.

(i) Outline the mechanism for this reaction.

(ii) Identify the minor product formed in this reaction.

.....

(iii) Explain why 2-bromopentane is the major product of this reaction.

.....

.....

.....

(7)
(Total 12 marks)

Q14. 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)

Q15. 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.

$$C_2H_6 + Cl_2 \longrightarrow C_2H_5Cl + HCl$$

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

(Total 5 marks)

Q16. Consider the following reaction in which an alkene is formed from a haloalkane.

$$CH_3CHBrCH_2CH_3 + KOH \xrightarrow[\text{ethanol solvent}]{\text{heat}} \underset{\text{but-2-ene}}{CH_3CH{=}CHCH_3} + KBr + H_2O$$

(a) Name the haloalkane used in this reaction.

.....

(1)

(b) Name and outline a mechanism for this reaction.

Name of mechanism .....

Mechanism

(4)

(c) Another alkene, which is a structural isomer of but-2-ene, is also formed during this reaction.

(i) State what is meant by the term *structural isomers*.

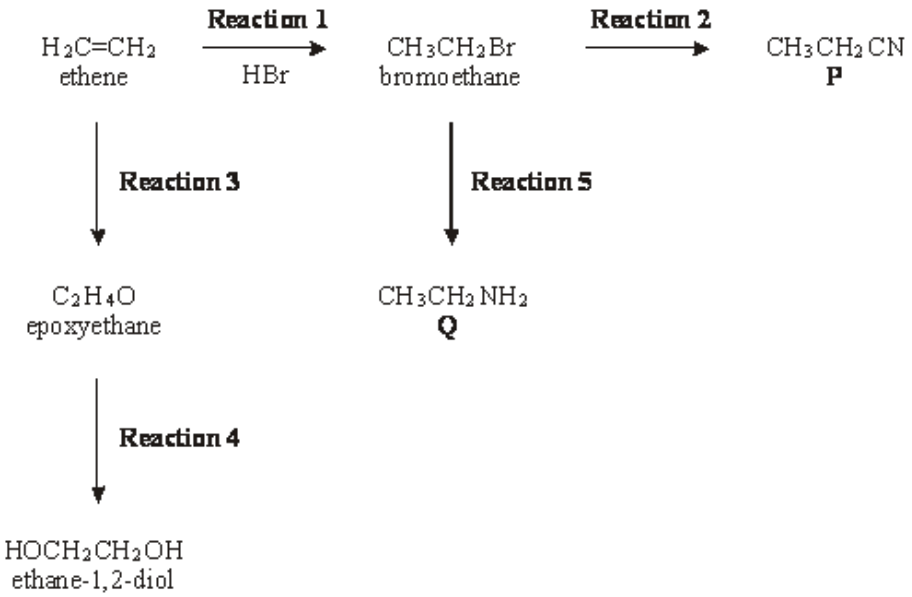
.....

.....

(ii) Draw the structure of this other alkene.

(2)
(Total 7 marks)

Q17. Consider the following scheme of reactions.



(a) In **Reaction 1**, ethene undergoes electrophilic addition with hydrogen bromide.

(i) State what is meant by the term *electrophile*.

.....

.....

(ii) Outline a mechanism for this reaction.

(5)

(b) Epoxyethane is formed from ethene in **Reaction 3**.

(i) Identify a reagent and a catalyst for this reaction.

Reagent .....

Catalyst .....

(ii) Draw the structure of epoxyethane.

(iii) Identify a reagent which will react with epoxyethane to form ethane-1,2-diol in **Reaction 4**.

.....

(4)

(c) In **Reactions 2** and **5**, bromoethane undergoes nucleophilic substitution.

(i) Identify a reagent for **Reaction 2**. Name the organic product, **P**.

*Reagent for **Reaction 2*** .....

*Name of product **P*** .....

(ii) Identify a reagent for **Reaction 5**. Name the organic product, **Q**.

*Reagent for **Reaction 5*** .....

*Name of product **Q*** .....

(iii) Outline a mechanism for **Reaction 5**.

(8)
(Total 17 marks)

Q18. (a) Name and outline a mechanism for the reaction of 2-bromo-2-methylpropane with ethanolic potassium hydroxide to form the alkene 2-methylpropene, $(CH_3)_2C{=}CH_2$

Name of mechanism .....

Mechanism

(4)

(b) Two stereoisomers of but-2-ene are formed when 2-bromobutane reacts with ethanolic potassium hydroxide.

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

.....

.....

(ii) Draw the structures and give the names of the **two** stereoisomers of but-2-ene.

Stereoisomer 1 *Stereoisomer 2*

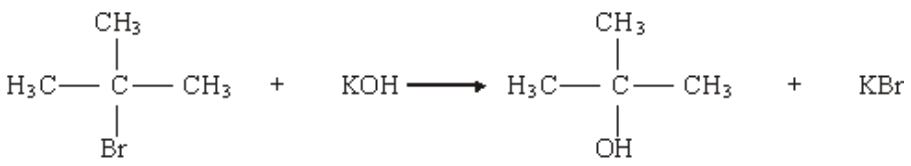
Name ..... *Name* .....

(iii) Name this type of stereoisomerism.

.....

(5)

(c) When 2-bromo-2-methylpropane reacts with aqueous potassium hydroxide, 2-methylpropan-2-ol is formed as shown by the following equation.



State the role of the hydroxide ions in this reaction.

.....

(1)

(d) Write an equation for the reaction that occurs when $CH_3CH_2CH_2CH_2Br$ reacts with an excess of ammonia. Name the organic product of this reaction.

Equation .....

Name of product .....

(3)
(Total 13 marks)

Q19. (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)

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.

Step **1** $Br_2 \longrightarrow 2Br^{\bullet}$

Step **2** $Br^{\bullet} + CH_3CH_3 \longrightarrow CH_3CH_2^{\bullet} + HBr$

Step **3** $CH_3CH_2^{\bullet} + Br_2 \longrightarrow CH_3CH_2Br + Br^{\bullet}$

(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.

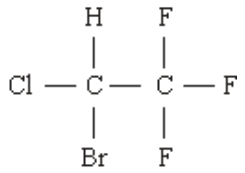
.....

(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) Bromoethane, CH_3CH_2Br, reacts with sodium hydroxide in an elimination reaction to form ethene.

(i) Outline a mechanism for this elimination reaction.

(ii) Suggest **one** reason why this method for making ethene is not used in industry.

.....

.....

(4)

(b) Ethene is used to make epoxyethane.

(i) State why epoxyethane is very reactive.

.....

.....

(ii) Identify the product formed when one molecule of epoxyethane reacts with one molecule of water. Give a use for this product.

Product.....

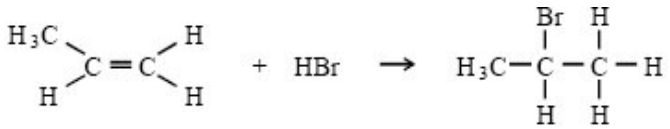
Use .....

(3)
(Total 7 marks)

Q22. Organic reaction mechanisms help to develop an understanding of how and why reactions occur.

(a) Propene reacts with hydrogen bromide by an electrophilic addition mechanism forming 2-bromopropane as the major product.

The equation for this reaction is shown below.



(i) Outline the mechanism for this reaction, showing the structure of the intermediate carbocation formed.

(ii) Give the structure of the alternative carbocation which could be formed in the reaction between propene and hydrogen bromide.

(5)

(b) A substitution reaction occurs when 2-bromopropane reacts with aqueous sodium hydroxide.

(i) Draw the structure of the organic product of this reaction and give its name.

Structure

Name .....

(ii) Name and outline the mechanism for this reaction.

Name of mechanism .....

Mechanism

(5)

(c) Under different conditions, 2-bromopropane reacts with sodium hydroxide to produce propene.

(i) Name the mechanism for this reaction

.....

(ii) State the role of sodium hydroxide in this reaction

.....

(2)
(Total 12 marks)

Q23. 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*.

.....

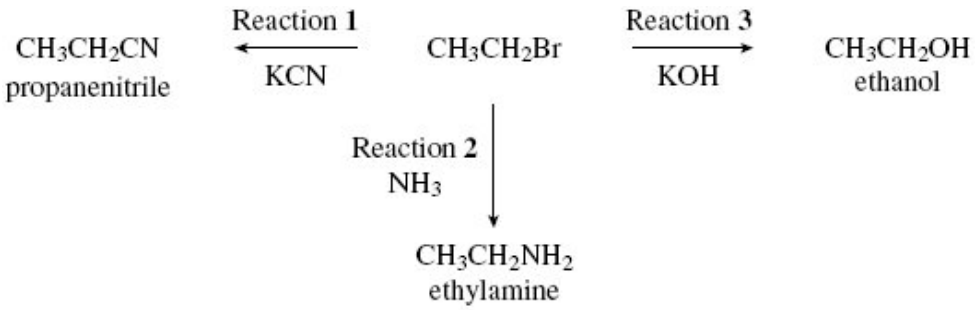
.....

.....

.....

(2)
(Total 13 marks)

Q24. Nucleophiles react with bromoethane in substitution reactions. This type of reaction is illustrated in the following scheme.



(a) State what is meant by the term *nucleophile*.

.....

(1)

(b) Outline a mechanism for the reaction of potassium cyanide with bromoethane (Reaction **1**).

(2)

(c) Explain why an excess of ammonia is needed in Reaction **2** to produce a high yield of ethylamine.

.....

.....

(1)

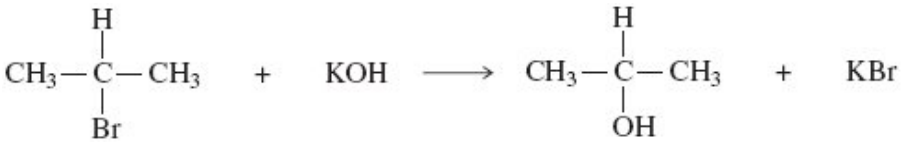
(d) When potassium hydroxide reacts with bromoethane, ethene can also be formed. Name and outline a mechanism for this reaction.

Name of mechanism .....

Mechanism

(4)
(Total 8 marks)

Q25. (a) Consider the following reaction.



(i) Name and outline a mechanism for this reaction.

Name of mechanism .....

Mechanism

(3)

(ii) Name the haloalkane in this reaction.

.....

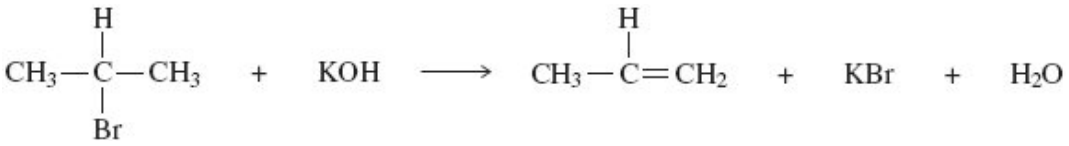
(1)

(iii) Identify the characteristic of the haloalkane molecule that enables it to undergo this type of reaction.

.....

(1)

(b) An alternative reaction can occur between this haloalkane and potassium hydroxide as shown by the following equation.



Name and outline a mechanism for this reaction.

Name of mechanism .....

Mechanism

(4)

(c) Give **one** condition needed to favour the reaction shown in part (b) rather than that shown in part (a).

.....

(1)

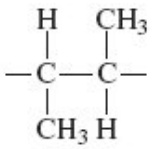
(d) Alkenes can be polymerised to produce poly(alkenes).

(i) State the type of polymerisation that alkenes undergo.

.....

(1)

(ii) Name the alkene that gives a polymer with the repeating unit shown below.

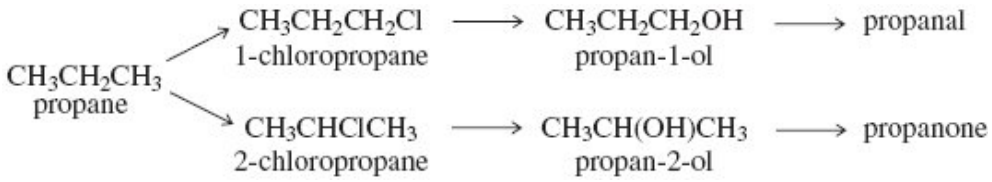


Name of alkene .....

(1)

(Total 12 marks)

Q26. 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}.
You may find it helpful to refer to **Table 1** on the Data Sheet.

.....

(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 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)

Q27. Chlorine is a useful industrial chemical.

(a) Chlorine gas is used in the manufacture of chlorine-containing organic compounds.

(i) Write equations for the following steps in the mechanism for the reaction of chlorine with ethane to form chloroethane (CH_3CH_2Cl).

Initiation step

.....

First propagation step

.....

Second propagation step

.....

A termination step producing butane.

.....

(4)

(ii) Give **one** essential condition and name the type of mechanism in this reaction of chlorine with ethane.

Essential condition .....

Type of mechanism .....

(2)

(b) Chlorine reacts with cold water.

(i) Write an equation for this reaction.

.....

(1)

(ii) Give **one** large-scale application of the use of chlorine in water. Explain why it is used in this application even though chlorine is very toxic. Do **not** include cost.

Example of application….....

Explanation of use .....

(2)

(iii) Two different chlorine-containing compounds are formed when chlorine reacts with cold, dilute sodium hydroxide solution. One of these compounds is sodium chloride. Name the other chlorine-containing compound formed.

.....

(1)

(c) Chlorine is used in the extraction of bromine from seawater.

(i) Write the **simplest** ionic equation for the reaction of chlorine with bromide ions.

.....

(1)

(ii) Explain why bromine has a higher boiling point than chlorine.

.....

.....

.....

(2)
(Total 13 marks)

Q28. A student carried out an experiment to study the rates of hydrolysis of some haloalkanes.

(a) In the experiment, two different haloalkanes were placed in separate test tubes containing silver nitrate solution. The haloalkanes reacted with the water in the silver nitrate solution. The student timed how long it took for the first appearance of the silver halide precipitate in each tube at a constant temperature. This time was used to provide a measure of the initial rate of reaction.
The student obtained the following results.

	1-bromobutane	1-iodobutane
Time to form a precipitate / s	480	15

(i) State the meaning of the term *hydrolysis*.

.....

.....

(1)

(ii) State the colour of the precipitate formed when iodide ions react with silver nitrate and write the **simplest** ionic equation for this reaction.

Colour of precipitate .....

Simplest ionic equation

.....

(2)

(iii) Use your knowledge of the reactions of halide ions with silver nitrate to suggest why the student did **not** include 1-fluorobutane in this experiment.

.....

.....

(2)

(b) The student used the following enthalpy data to try to account for the different initial rates of hydrolysis of the haloalkanes used in part (a). The student deduced that the rate of hydrolysis of a haloalkane is influenced by the strength of the carbon–halogen bond in the haloalkane.

	C–Br	C–I
Bond enthalpy / kJ mol^{-1}	276	238

State how the experimental evidence enabled the student to make this deduction.

.....

.....

(1)

(c) The student had read that the reaction of water with haloalkanes was similar to the reaction of aqueous sodium hydroxide with haloalkanes and was an example of a nucleophilic substitution reaction.

(i) State the meaning of the term *nucleophile*.

.....

(1)

(ii) When a hydroxide ion collides with a molecule of 1-bromobutane, the following reaction occurs.

$$CH_3CH_2CH_2CH_2Br + OH^- \rightarrow CH_3CH_2CH_2CH_2OH + Br^-$$

Outline the nucleophilic substitution mechanism for this reaction.

(2)

(d) The reaction of hydroxide ions with 2-bromo-2-methylpropane may occur by a different mechanism from the one in part (c). This different mechanism involves the formation of a carbocation.

(i) Complete the following equation by drawing the structure of the carbocation formed when the C–Br bond in 2-bromo-2-methylpropane is broken.

(1)

(ii) Suggest **one** reason why this reaction occurs by a mechanism involving a carbocation, but the reaction in part (c) (ii) does not.

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.....

(1)
(Total 11 marks)

Q29. A student read the following passage on the Internet.

Haloalkanes contain a polar covalent bond. The carbon atom of the polar covalent bond can be attacked by nucleophiles. Nucleophilic attack enables haloalkanes to undergo substitution reactions. A nucleophilic substitution reaction occurs when a haloalkane undergoes hydrolysis; the rate of hydrolysis of the haloalkane is influenced by the carbon–halogen bond enthalpy.

(a) Explain the meaning of each of the following terms in the information given above.

(i) *nucleophile*

.....

.....

.....

(1)

(ii) *substitution,* as applied to nucleophilic substitution in a haloalkane

.....

.....

.....

(1)

(iii) *hydrolysis*

.....

.....

.....

(1)

(iv) *bond enthalpy,* as applied to a carbon–halogen bond.

.....

.....

.....

(1)

(b) Outline a mechanism for the nucleophilic substitution reaction in which 2-bromopropane ($CH_3CHBrCH_3$) reacts with potassium hydroxide to form propan-2-ol.

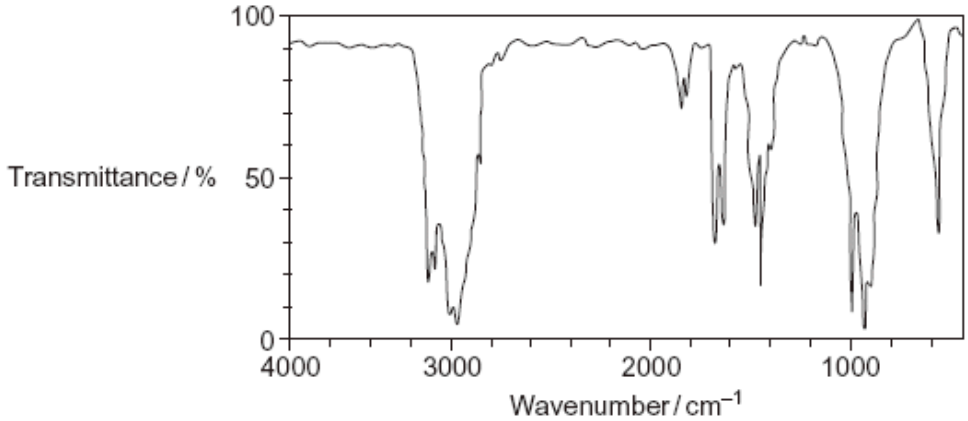
(2)

(c) Haloalkanes also undergo elimination reactions to produce alkenes.

(i) Outline a mechanism for the elimination reaction in which 2-bromopropane reacts with potassium hydroxide to form propene.

(3)

(ii) A student obtained the following infrared spectrum for the product from this elimination reaction.



Use information from the infrared spectrum to state and explain how the student deduced that the product was an alkene.
You may find it helpful to refer to **Table 1** on the Data Sheet.

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(2)
(Total 11 marks)

Q30. (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)

Q31. Oxygen and ozone (O_3) both occur as gases in the upper atmosphere.

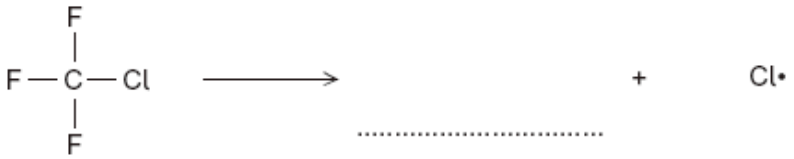
Chlorine atoms catalyse the decomposition of ozone and contribute to the formation of a hole in the ozone layer.
These chlorine atoms are formed from chlorofluorocarbons (CFCs) such as CF_3Cl

(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.

.....

.....

.....

(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)

Q32. Organic reaction mechanisms help chemists to understand how the reactions of organic compounds occur.
The following conversions illustrate a number of different types of reaction mechanism.

(a) When 2-bromopentane reacts with ethanolic KOH, two structurally isomeric alkenes are formed.

(i) Name and outline a mechanism for the conversion of 2-bromopentane into pent-2-ene as shown below.

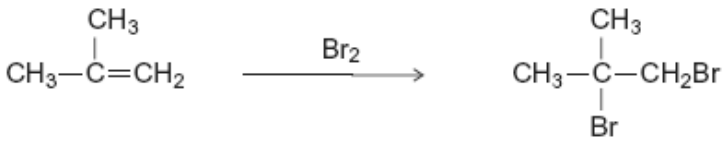
$$CH_3CH_2CH_2CHBrCH_3 \xrightarrow{\text{ethanolic KOH}} CH_3CH_2CH{=}CHCH_3$$

(4)

(ii) Draw the structure of the other structurally isomeric alkene produced when 2-bromopentane reacts with ethanolic KOH.

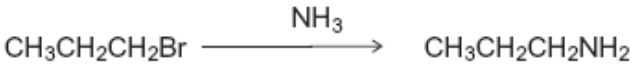
(1)

(b) Name and outline a mechanism for the following conversion.



(5)

(c) Name and outline a mechanism for the following conversion.



(5)
(Total 15 marks)

Q33. 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)