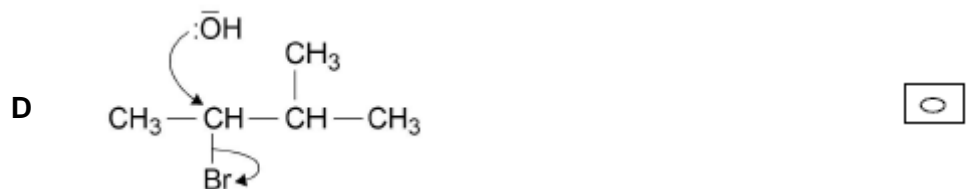
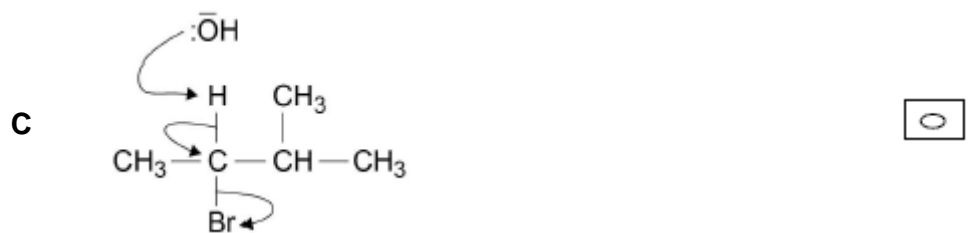
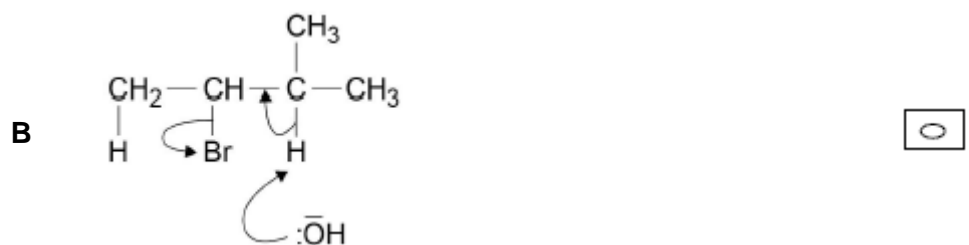
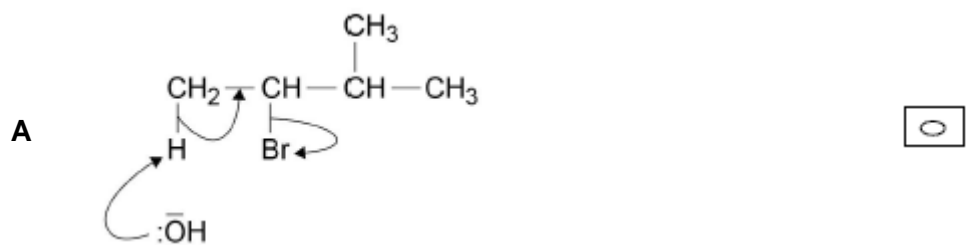


1

Which of the following is a correct mechanism for the formation of 2-methylbut-2-ene from 2-bromo-3-methylbutane?



(Total 1 mark)

2

2-bromo-2-methylpentane is heated with potassium hydroxide dissolved in ethanol. Two structural isomers are formed.

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

.....
.....
.....

(1)

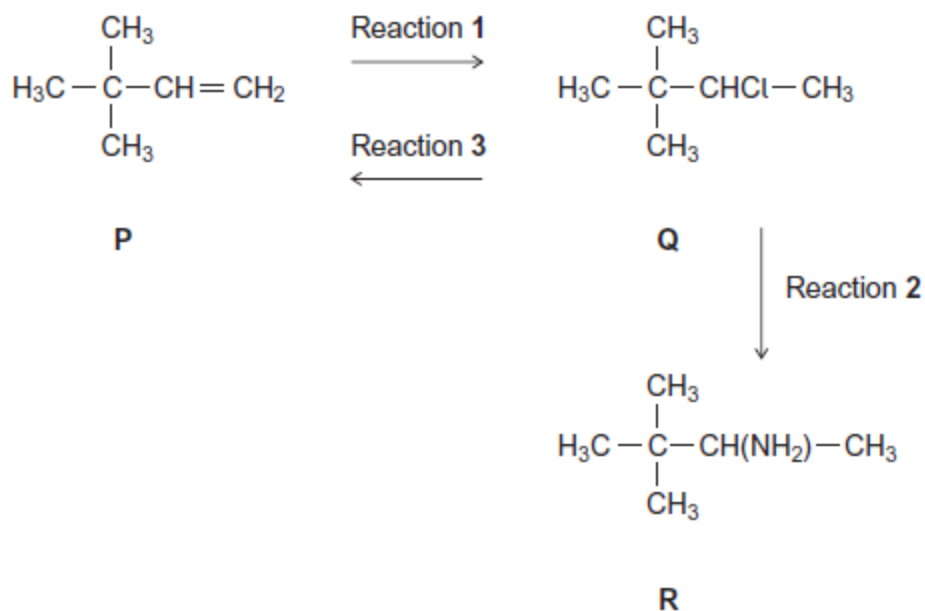
(b) Name and draw the mechanism for the formation of **one** of the isomers.

Name of mechanism

Mechanism

(5)
(Total 6 marks)

3 Consider the following scheme of reactions.



(a) Give the IUPAC name for compound **P** and that for compound **Q**.

P

Q

(2)

(b) The conversion of **P** into **Q** in Reaction 1 uses HCl

Name and outline a mechanism for this reaction.

.....

(5)

(c) The conversion of **Q** into **R** in Reaction 2 uses NH₃

Name and outline a mechanism for this reaction.

.....

(5)

(d) State the type of reaction shown by Reaction 3.

Identify a reagent for this reaction.

Give **one** condition necessary for a high yield of product when **Q** is converted into **P**.

.....

.....

.....

.....

.....

(3)

- (e) Hydrogen bromide (HBr) could be used in the overall conversion of **P** into **R**, instead of using HCl

Hydrogen bromide is made by the reaction of NaBr with concentrated phosphoric acid. Concentrated sulfuric acid is **not** used to make HBr from NaBr

Write an equation for the reaction of NaBr with H₃PO₄ to produce HBr and Na₃PO₄ only.

Identify **two** toxic gases that are formed, together with HBr, when NaBr reacts with concentrated H₂SO₄

State the role of H₂SO₄ in the formation of these two toxic gases.

.....

.....

.....

.....

.....

.....

.....

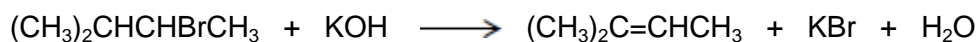
(4)
(Total 19 marks)

4

Haloalkanes are used in the synthesis of other organic compounds.

- (a) Hot concentrated ethanolic potassium hydroxide reacts with 2-bromo-3-methylbutane to form two alkenes that are structural isomers of each other. The major product is 2-methylbut-2-ene.

- (i) Name and outline a mechanism for the conversion of 2-bromo-3-methylbutane into 2-methylbut-2-ene according to the equation.



Name of mechanism

Mechanism

(4)

(ii) Draw the **displayed formula** for the other isomer that is formed.

(1)

(iii) State the type of structural isomerism shown by these two alkenes.

.....

(1)

(b) A small amount of another organic compound, **X**, can be detected in the reaction mixture formed when hot concentrated ethanolic potassium hydroxide reacts with 2-bromo-3-methylbutane.

Compound **X** has the molecular formula $C_5H_{12}O$ and is a secondary alcohol.

(i) Draw the **displayed formula** for **X**.

(1)

(ii) Suggest **one** change to the reaction conditions that would increase the yield of **X**.

.....

.....

(1)

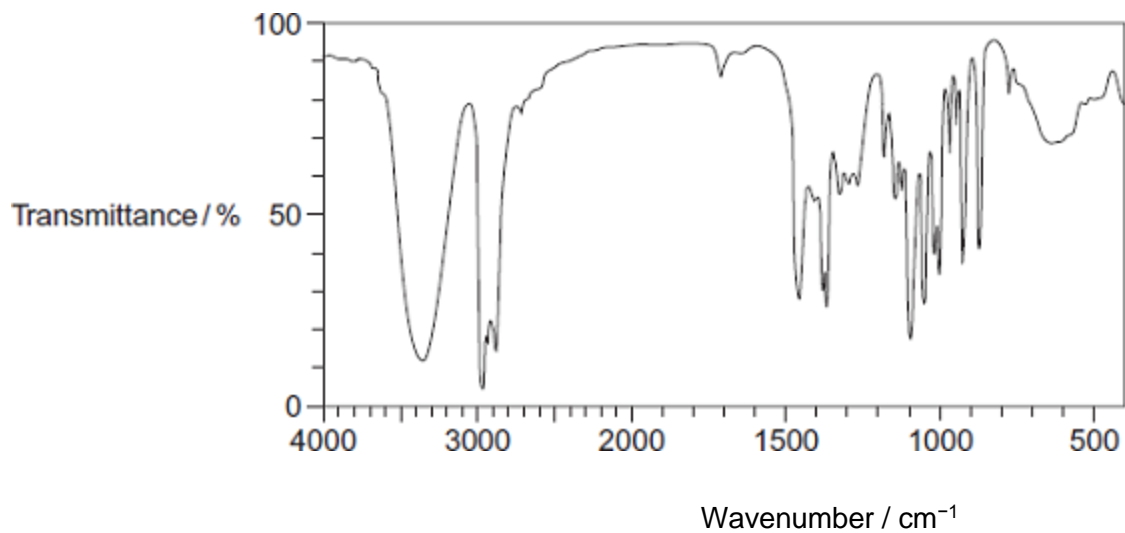
(iii) State the type of mechanism for the conversion of 2-bromo-3-methylbutane into **X**.

.....

(1)

(iv) Identify **one** feature of this infrared spectrum of a pure sample of **X** that may be used to confirm that **X** is an alcohol.

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



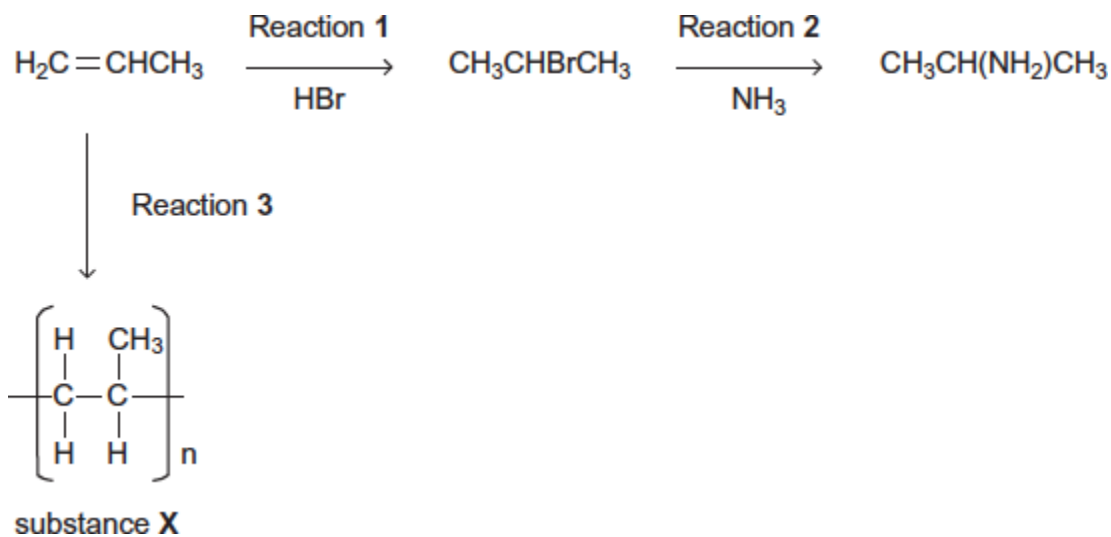
Feature

.....

(1)
(Total 10 marks)

5

Consider the following reactions.



(a) Name and outline a mechanism for Reaction 1.

Name of mechanism

Mechanism

(5)

(b) Name and outline a mechanism for Reaction 2.

Name of mechanism

Mechanism

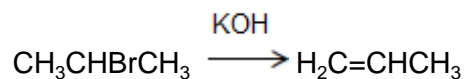
(5)

- (c) State the type of reaction in Reaction 3.
Give the name of substance X.

.....

(2)

- (d) The haloalkane produced in Reaction 1 can be converted back into propene in an elimination reaction using ethanolic potassium hydroxide.



Outline a mechanism for this conversion.

(3)

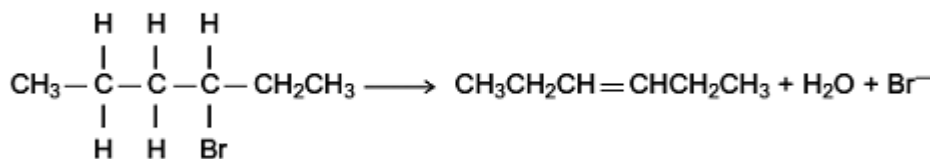
(Total 15 marks)

6

Alkenes are useful intermediates in the synthesis of organic compounds.

- (a) (i) Complete the elimination mechanism by drawing appropriate curly arrows.

HO^- :



3-bromohexane

hex-3-ene

(3)

(ii) Draw structures for the E and Z stereoisomers of hex-3-ene.

E isomer of hex-3-ene

Z isomer of hex-3-ene

(2)

(iii) State the meaning of the term *stereoisomers*.

.....
.....
.....
.....
.....
(Extra space)
.....

(2)

(b) The equation for the first reaction in the conversion of hex-3-ene into hexan-3-ol is shown below.



Outline a mechanism for this reaction.

(4)
(Total 11 marks)

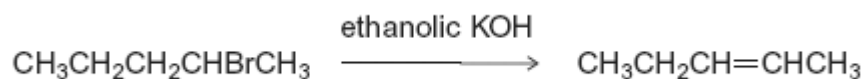
7

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.

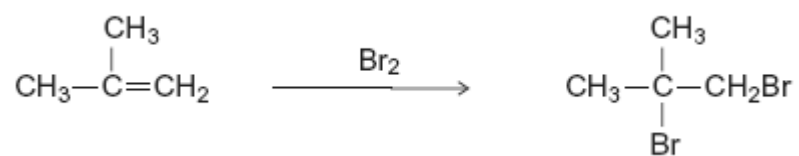


(4)

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

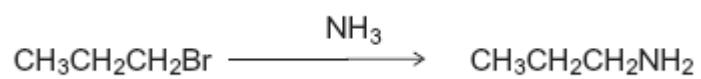
(1)

(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)

8

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 ($\text{CH}_3\text{CHBrCH}_3$) reacts with potassium hydroxide to form propan-2-ol.

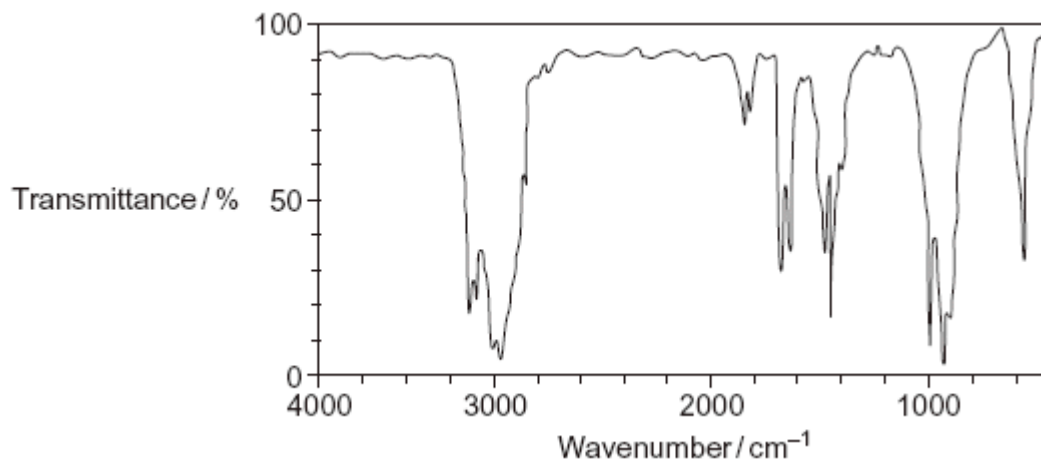
(2)

- (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.

.....

.....

.....

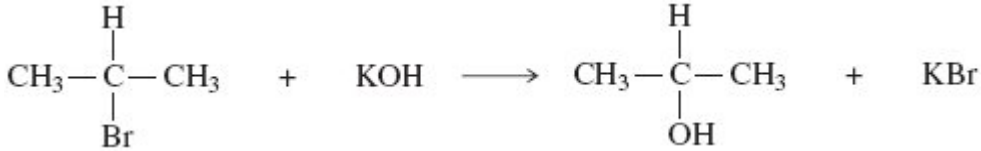
.....

.....

(2)
(Total 11 marks)

9

(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.

.....

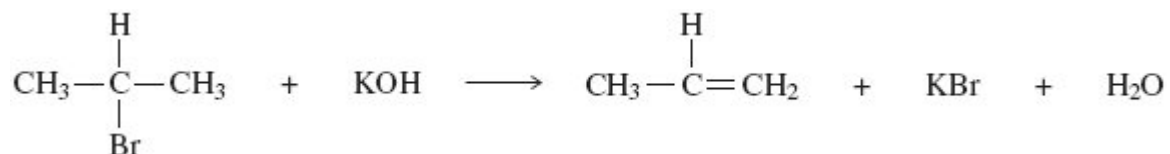
(1)

(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)

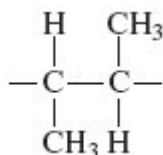
- (d) Alkenes can be polymerised to produce poly(alkenes).

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

.....

(1)

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



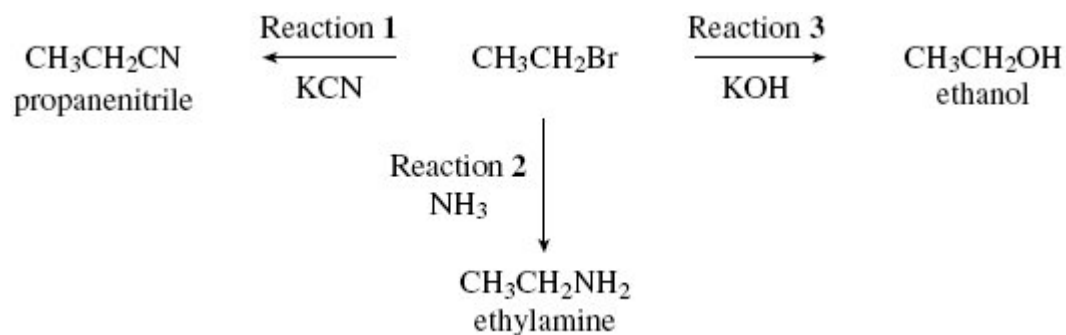
Name of alkene

(1)

(Total 12 marks)

10

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

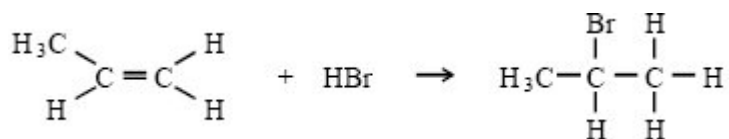
(4)
(Total 8 marks)

11

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)

12

How many different alkenes are formed when 2-bromo-3-methylbutane reacts with ethanolic potassium hydroxide?

A 2

B 3

C 4

D 5

(Total 1 mark)

13

- (a) Name and outline a mechanism for the reaction of 2-bromo-2-methylpropane with ethanolic potassium hydroxide to form the alkene 2-methylpropene, $(\text{CH}_3)_2\text{C}=\text{CH}_2$

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

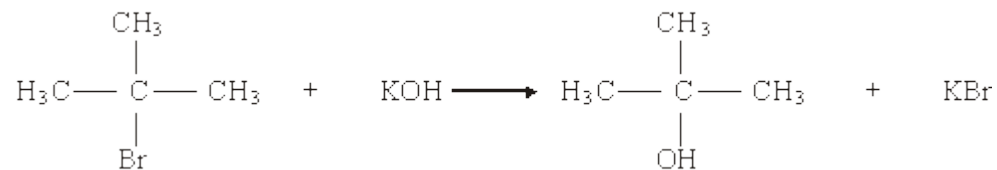
Name Name

- (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 $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{Br}$ reacts with an excess of ammonia. Name the organic product of this reaction.

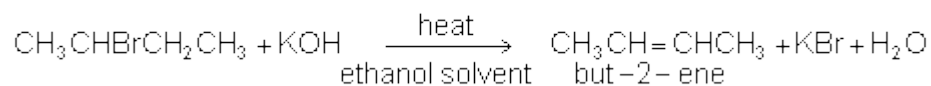
Equation

Name of product

(3)
(Total 13 marks)

14

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



- (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)

15

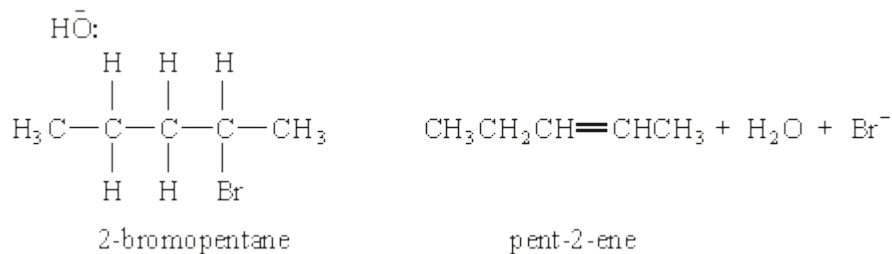
How many different alkenes are formed when 2-bromo-2-methylbutane reacts with ethanolic potassium hydroxide?

- A 2
- B 3
- C 4
- D 5

(Total 1 mark)

16

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



(3)

(b) Draw and name the geometrical E-Z 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.

.....

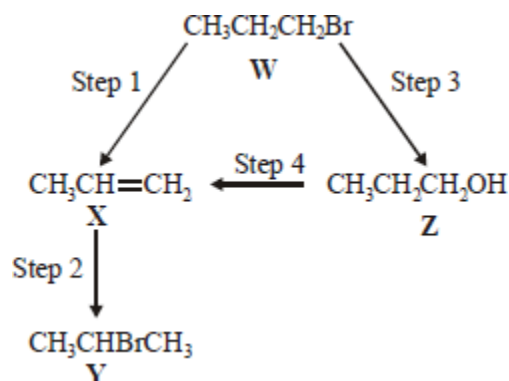
.....

.....

(7)
(Total 12 marks)

17

For this question refer to the reaction scheme below.



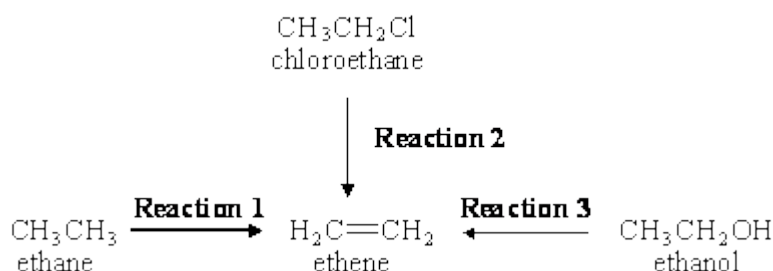
Which one of the following reagents would **not** bring about the reaction indicated?

- A Step 1 : alcoholic KOH
 B Step 2 : aqueous Br₂
 C Step 3 : aqueous NaOH
 C Step 4 : concentrated H₂SO₄

(Total 1 mark)

18

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)

(6)
 (Total 15 marks)

19

(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

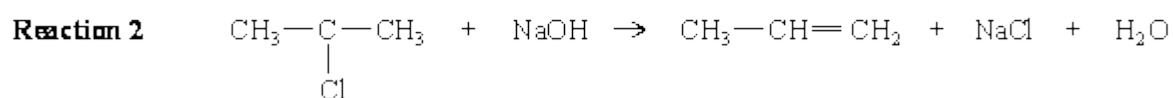
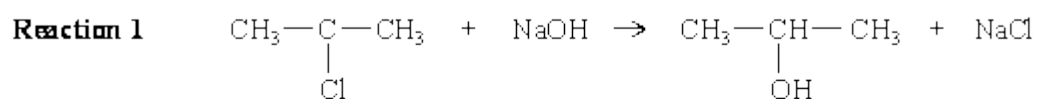
Isomer 2

(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.



(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

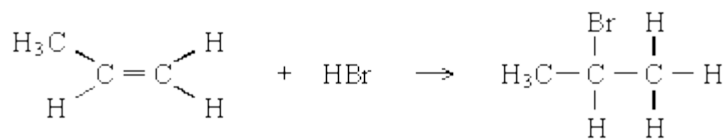
Role of the hydroxide ion

(7)
(Total 10 marks)

20

- (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.

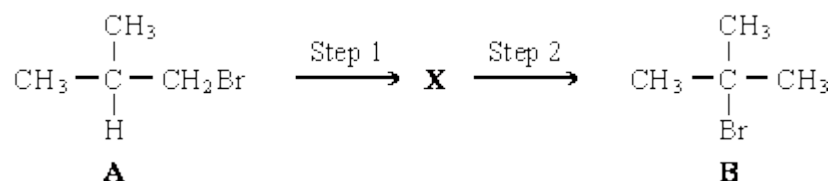
.....

(2)

(Total 12 marks)

21

The conversion of compound **A** into compound **B** can be achieved in two steps as shown below.



The intermediate compound, **X**, has an absorption at 1650 cm^{-1} in its infra-red spectrum.

(a) Identify compound **X**. Explain your answer.

(2)

(b) For each step in this conversion, give the reagents and essential conditions required and outline a mechanism.

(11)

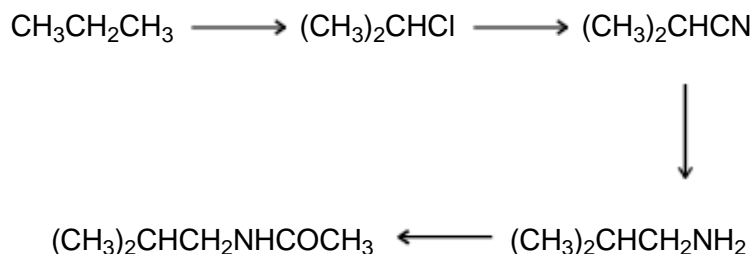
(c) Show how the number of peaks in their proton n.m.r. spectra would enable you to distinguish between compounds **A** and **B**.

(2)

(Total 15 marks)

22

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)

23

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)

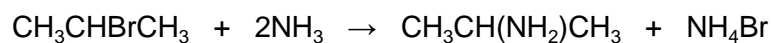
- (c) When 2-bromobutane reacts with ethanolic potassium hydroxide, two structurally isomeric alkenes are produced, one of which shows stereoisomerism.

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)

24

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



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)

25

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 (CF₃CH₃).

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)

26

CCl₄ is an effective fire extinguisher but it is no longer used because of its toxicity and its role in the depletion of the ozone layer. In the upper atmosphere, a bond in CCl₄ breaks and reactive species are formed.

- (a) Identify the condition that causes a bond in CCl₄ to break in the upper atmosphere. Deduce an equation for the formation of the reactive species.

Condition

Equation

.....

(2)

- (b) One of the reactive species formed from CCl₄ acts as a catalyst in the decomposition of ozone.

Write **two** equations to show how this species acts as a catalyst.

Equation 1

.....

Equation 2

.....

(2)

- (c) A small amount of the freon CF_3Cl with a mass of 1.78×10^{-4} kg escaped from a refrigerator, into a room of volume 100 m^3 . Assuming that the freon is evenly distributed throughout the air in the room, calculate the number of freon molecules in a volume of 500 cm^3 .

Give your answer to the appropriate number of significant figures.

The Avogadro constant = $6.02 \times 10^{23} \text{ mol}^{-1}$.

Number of molecules =

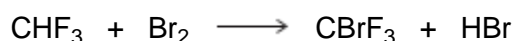
(3)

(Total 7 marks)

27

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 CHF_3 with Br_2

Initiation step

.....

First propagation step

.....

Second propagation step

.....

A termination step

.....

(4)

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

.....

(1)

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

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



.....

(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 (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)

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, CHF_3 has replaced CClF_3 because of concerns about ozone depletion.

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

.....

(1)

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

.....

(1)
(Total 7 marks)

29

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 (CH₃Cl) with chlorine to form dichloromethane (CH₂Cl₂).

Initiation step

.....

First propagation step

.....

Second propagation step

.....

The termination step that forms a compound with empirical formula CH₂Cl.

.....

(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)

30

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)

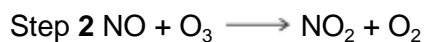
(c) Nitrogen monoxide (NO) catalyses the decomposition of ozone into oxygen.

(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.



Step 3

(1)

(Total 9 marks)

31

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.

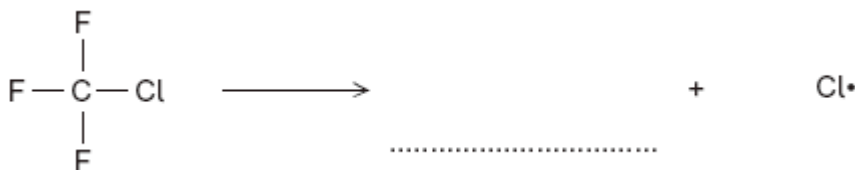
These chlorine atoms are formed from chlorofluorocarbons (CFCs) such as CF_3Cl

(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 \cdot represents in $Cl\cdot$

.....

(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.

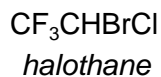
.....
.....

(1)

(Total 9 marks)

32

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).

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(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.

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(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)

Mark schemes

1 B

[1]

2 (a) (Compounds with the) same molecular formula but different structural / displayed / skeletal formula

1

(b) (basic) elimination

1

Mechanism points:

Correct arrow from lone pair on :OH^- to H on C adjacent to C-Br

1

Correct arrow from C-H bond to C-C

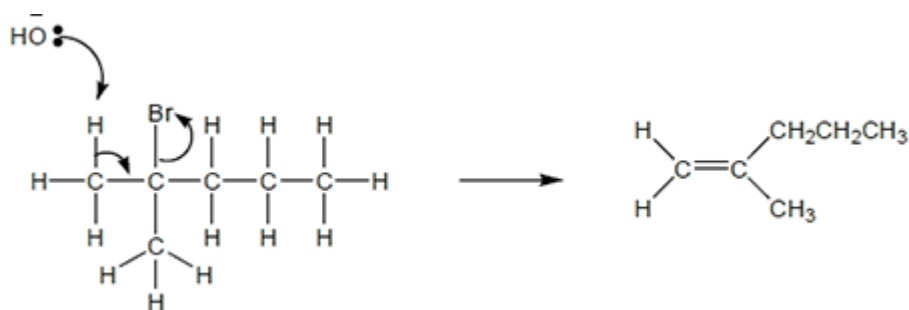
1

Correct arrow from C-Br bond to Br

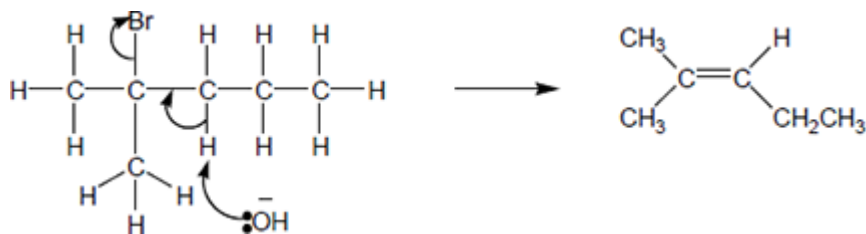
1

Structure of chosen product

1



OR



[6]

3(a) **P** 3,3-dimethylbut-1-ene**OR**

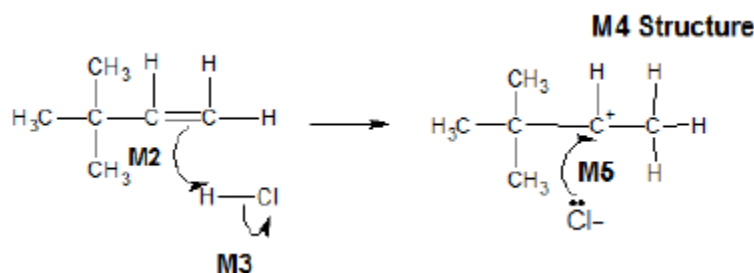
accept 3,3-dimethylbutene

*Ignore absence of commas, hyphens and gaps**Require correct spelling***Q** 3-chloro-2,2-dimethylbutane**OR**

accept 2-chloro-3,3-dimethylbutane

In Q, "chloro" must come before "dimethyl"

2

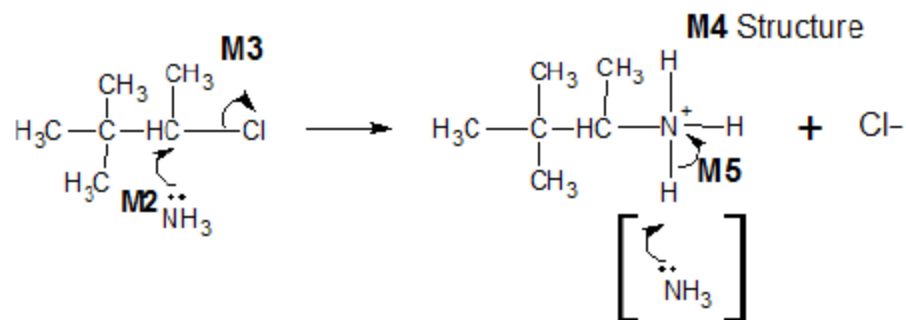
(b) **M1** Electrophilic addition**M2** must show an arrow from the double bond towards the H atom of HCl**M3** must show the breaking of the H-Cl bond**M4** is for the structure of the carbocation**M5** must show an arrow from the lone pair of electrons on the negatively charged chloride ion towards the positively charged carbon atom on their carbocation.**NB** The arrows here are double-headed*M1 both words required***For the mechanism***M3 Penalise incorrect partial charge on H-Cl bond and penalise formal charges**Ignore partial negative charge on the double bond.***Maximum 3 of 4 marks for a correct mechanism** using HBr or the wrong organic reactant or wrong organic product (if shown) or a primary carbocation*Penalise once only in any part of the mechanism for a line and two dots to show a bond**Credit the correct use of "sticks"**For M5, credit attack on a partially positively charged carbocation structure, but penalise M4*

5

(c) **M1 Nucleophilic substitution**

For **M1**, both words required.

Accept phonetic spelling



M2 must show an arrow from the lone pair of electrons **on the nitrogen atom** of an ammonia molecule to the correct C atom

M3 must show the movement of a pair of electrons from the C–Cl bond to the Cl atom. Mark **M3** independently provided it is from their original molecule

M4 is for the structure of the alkylammonium ion, which could be a condensed formula. A positive charge **must** be shown on, or close to, the N atom.

M5 is for an arrow from the N–H bond to the N atom

Award full marks for an S_N1 mechanism in which **M2** is the attack of the ammonia on the intermediate carbocation

NB These are double-headed arrows

For the mechanism

Penalise **M2** if NH_3 is negatively charged.

Penalise **M3** for formal charge on C of the C–Cl or incorrect partial charges on C–Cl

Penalise **M3** for an additional arrow from the Cl to something else

The second mole of ammonia is not essential for **M5**; therefore ignore any species here

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

Maximum 3 of 4 marks for the mechanism for wrong organic reactant OR wrong organic product if shown

Accept the correct use of “sticks”

(d) **M1** (base) elimination

***M1** Dehydrohalogenation*

M2 KOH **OR** NaOH

M3 Must be consequential on a correct reagent in **M2**, but if incomplete or inaccurate attempt at reagent (e.g. hydroxide ion), **penalise M2 only and mark on**

Any **one** from

- high temperature **OR** hot **OR** heat / boil under reflux
- concentrated
- alcohol / ethanol (as a solvent) / (ethanolic conditions)

***M3** not “reflux” alone*

***M3** if a temperature is stated it must be in the range 78°C to 200 °C*

Ignore “pressure”

3

(e) **M1**



***M1** Credit correct ionic species in the equation*

M2 and M3

SO₂ **and** Br₂ identified

M4

Concentrated sulfuric acid

- is an oxidising agent
- oxidises the bromide (ion) or Br⁻ or NaBr or HBr
- is an electron acceptor

*In **M2** and **M3** the two gases need to be identified. If equations are used using sulfuric acid and the toxic gases are not identified clearly, allow one mark for the formulas of SO₂ and Br₂*

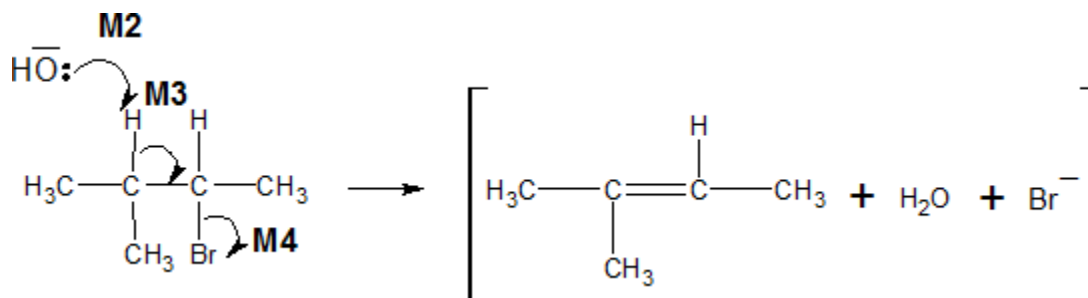
- *apply the list principle as appropriate but ignore any reference to HBr*
- *the marks are for identifying the two gases either by name or formula*

4

[19]

4

(a) (i) M1 Elimination

M1 Credit "base elimination" but no other prefix.*Penalise M2 if covalent KOH**Penalise M4 for formal charge on C or Br of C-Br or incorrect partial charges on C-Br*

M2 must show an arrow from the lone pair on the oxygen of a negatively charged hydroxide ion to a correct H atom

Ignore other partial charges

M3 must show an arrow from a correct C-H bond adjacent to the C-Br bond to a correct C-C bond. Only award if an arrow is shown attacking the H atom of a correct adjacent C-H bond in **M2**

*Penalise **once only** in any part of the mechanism for a line and two dots to show a bond*

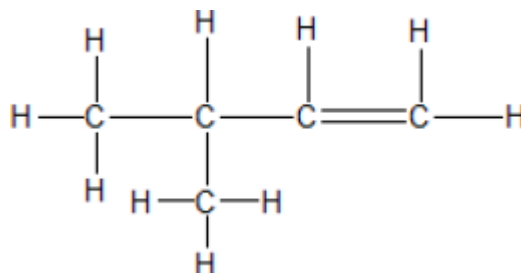
M4 is independent provided it is from their original molecule, **BUT CE=0 for the mechanism (penalise M2, M3 and M4 only) if nucleophilic substitution mechanism is shown**

***Maximum any 2 of 3 marks for the mechanism** for wrong organic reactant or wrong organic product (if shown).**Credit the correct use of "sticks" for the molecule except for the C-H being attacked*

Award full marks for an E1 mechanism in which **M4** is on the correct carbocation

*Penalise **M4**, if an additional arrow is drawn from Br eg to K⁺***NB These are double-headed arrows**

4

(ii) Displayed formula for 3-methylbut-1-ene*All bonds and atoms must be drawn out, but ignore bond angles*

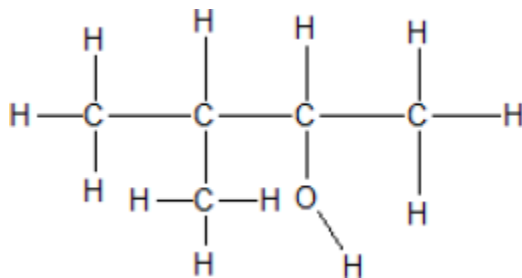
1

(iii) Position(al) (isomerism or isomer)

Penalise any other words that are written in addition to these.

1

(b) (i) Displayed formula for 3-methylbutan-2-ol



All bonds and atoms must be drawn out, but ignore bond angles.

1

(ii) Any **one** from

- Lower / decreased temperature **OR** cold
- Less concentrated (comparative) **OR** dilute KOH
- Water (as a solvent) / (aqueous conditions)
Ignore "pressure".

1

(iii) Nucleophilic substitution

Both words needed - credit phonetic spelling.

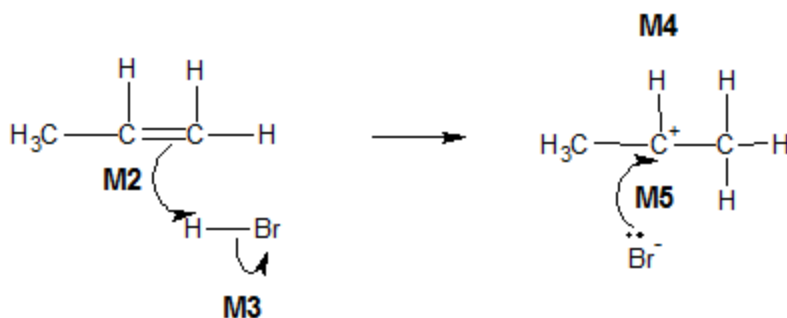
1

(iv) (Strong / broad) absorption / peak in the range **3230 to 3550** cm^{-1} or specified value in this range or marked correctly on spectrum

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

1

[10]

5**(a) M1 electrophilic addition***For M1, both words required**Accept phonetic spelling****For the mechanism*****M2** *Ignore partial negative charge on the double bond*

M2 must show an arrow from the double bond towards the H atom of the H-Br molecule

M3 *Penalise partial charges on H-Br bond if wrong way and penalise formal charges*

M3 must show the breaking of the H-Br bond

Penalise once only in any part of the mechanism for a line and two dots to show a bond

M5 must show an arrow from the lone pair of electrons on the negatively charged bromide ion towards the correct (positively charged) carbon atom

Maximum any 3 of 4 marks for the mechanism for wrong (organic) reactant **OR** wrong organic product (if shown) **OR** primary carbocation

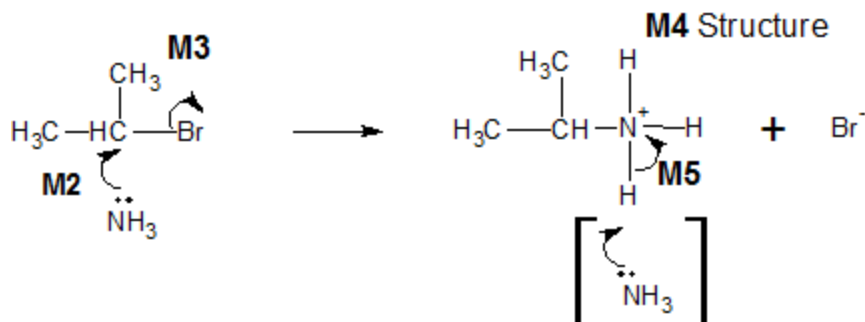
Accept the correct use of sticks

NB These are double-headed arrows

(b) **M1 Nucleophilic substitution**

For **M1**, both words required

Accept phonetic spelling



For the mechanism

Penalise **M2** if NH_3 is negatively charged

M2 must show an arrow from the lone pair of electrons **on the nitrogen atom** of an ammonia molecule to the correct C atom

Penalise **M3** for formal charge on C of the $\text{C}-\text{Br}$ or incorrect partial charges on $\text{C}-\text{Br}$

Penalise **M3** for an additional arrow from the Br to something else

M3 must show the movement of a pair of electrons from the $\text{C}-\text{Br}$ bond to the Br atom. Mark **M3** independently provided it is from their original molecule

The second mole of ammonia is not essential for **M5**; therefore ignore any species here

M4 is for the structure of the alkylammonium ion, which could be a condensed formula. A positive charge **must** be shown on / or close to, the N atom

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

M5 is for an arrow from the $\text{N}-\text{H}$ bond to the N atom

Maximum any 3 of 4 marks for the mechanism for

wrong organic reactant **OR** wrong organic product if shown

Award full marks for an $\text{S}_{\text{N}}1$ mechanism in which **M2** is the attack of the ammonia on the intermediate carbocation

Accept the correct use of "sticks"

NB These are double-headed arrows

5

(c) M1 (addition) polymerisation OR poly-addition

Ignore "additional"

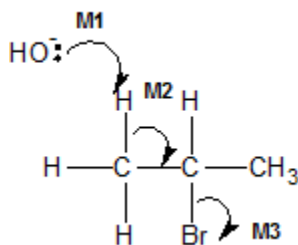
Credit polyprop-1-ene and polypropylene

M2 poly(propene) / polypropene

Penalise "condensation polymerisation"

2

(d)



Penalise **M1** if covalent KOH

M1 must show an arrow from the lone pair on the oxygen of a negatively charged hydroxide ion to a correct H atom

Penalise **M3** for formal charge on C of C-Br or incorrect partial charges on C-Br.

M2 must show an arrow from a correct C-H bond adjacent to the C-Br bond to the appropriate C-C bond. Only award if an arrow is shown attacking the H atom of a correct C-H bond in **M1**

Ignore other partial charges

Penalise once only in any part of the mechanism for a line and two dots to show a bond

M3 is independent provided it is from their original molecule, but **CE=0 if nucleophilic substitution**

Maximum any 2 of 3 marks for wrong organic reactant

Award full marks for an E1 mechanism in which **M3** is on the correct carbocation.

Accept the correct use of "sticks" for the molecule except for the C-H being attacked

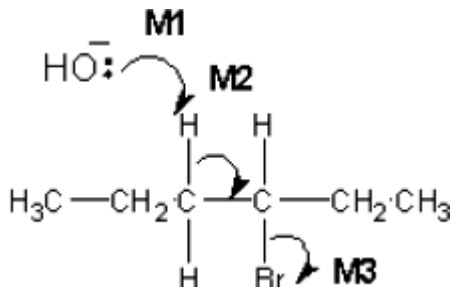
NB These are double-headed arrows

3

[15]

6

(a) (i)



Penalise one mark from their total if half-headed arrows are used

Penalise **M3** for formal charge on C of the C-Br or incorrect partial charges on C-Br

Ignore other partial charges

M1 must show an arrow from the lone pair on oxygen of a negatively charged hydroxide ion to the correct H atom

Penalise once only in any part of the mechanism for a line and two dots to show a bond.

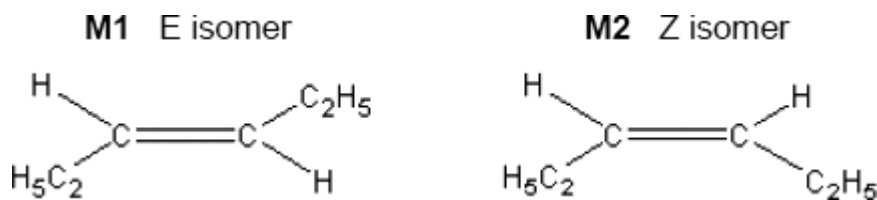
M2 must show an arrow from the correct C–H bond to the correct C–C bond. Only award if an arrow is shown attacking the H atom of the correct C–H bond in **M1**

M3 is independent but **CE=0** if nucleophilic substitution

N.B these are double-headed arrows

3

(ii)



*Award 1 mark if both correct stereoisomers but in the wrong places
Accept no other alkenes.*

Be reasonably lenient on the bonds to ethyl (or to CH₂CH₃) since the question is about E and Z positions but penalise once only if connection is clearly to the CH₃ of CH₂CH₃

Accept linear structures

2

(iii) **M1** (Compounds / molecules with) the same structural formula
*Penalise **M1** if “same structure”*

M2 with atoms/bonds/groups arranged differently in space
Ignore references to “same molecular formula” or “same empirical formula” or any reference to “displayed formula”

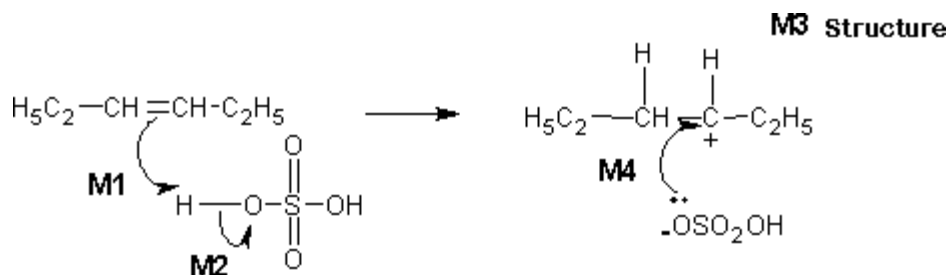
OR

atoms/bonds/groups that have different spatial arrangements / different orientation.

Mark independently

2

(b)



M1 must show an arrow from the double bond towards the H atom of the H – O bond
OR HO on a compound with molecular formula for H₂SO₄

M1 could be to an H⁺ ion and **M2** an independent O – H bond break on a compound with molecular formula for H₂SO₄

M1 Ignore partial negative charge on the double bond.

M2 must show the breaking of the O – H bond.

M2 Penalise partial charges on O – H bond if wrong way and penalise formal charges

In **M2** do not penalise incorrect structures for H₂SO₄

M3 is for the structure of the carbocation.

M4 must show an arrow from the lone pair of electrons on the correct oxygen of the negatively charged ion towards a correct (positively charged) carbon atom.

M4 NOT HSO₄⁻

For **M4**, credit as shown or ˙˙OSO₃H ONLY with the negative charge anywhere on this ion

OR correctly drawn out with the negative charge placed correctly on oxygen

Penalise once only in any part of the mechanism for a line and two dots to show a bond

NB The arrows here are double-headed

Max 3 of any 4 marks for wrong organic reactant or wrong organic product (if shown)

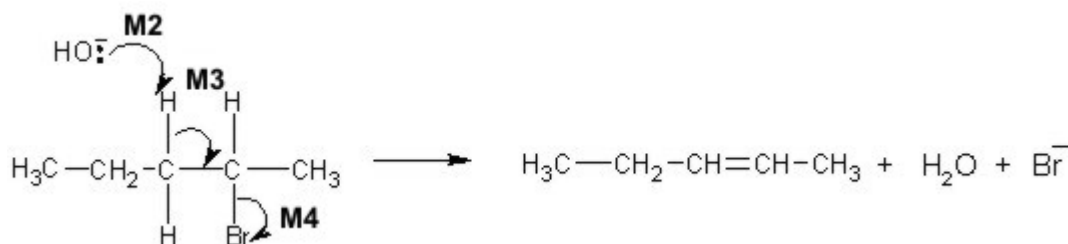
Accept the correct use of “sticks”

4

[11]

7

(a) (i) **M1** Elimination



M2 must show an arrow from the lone pair on the oxygen of a negatively charged hydroxide ion to a correct H atom

M3 must show an arrow from a C-H bond adjacent to the C-Br bond towards the appropriate C-C bond.
Only award if a reasonable attempt has been made at the attack on the H atom of the appropriate adjacent C-H

M4 is independent provided it is from their original molecule

Award full marks for an E1 mechanism in which **M3** is on the correct carbocation.

N.B. These are double-headed arrows

For M1, accept "Base elimination" but no other prefix.

*Penalise **M2** if covalent KOH*

*Penalise **M4** for formal charge on C of C-Br or incorrect partial charges on C-Br*

Ignore other partial charges

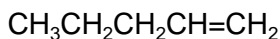
Penalise once only in any part of the mechanism for a line and two dots to show a bond.

Max any 2 of 3 marks for the mechanism for wrong reactant (or wrong product if shown).

Accept the correct use of "sticks" for the molecule except for the C-H being attacked

4

(ii) **Structure for pent-1-ene**

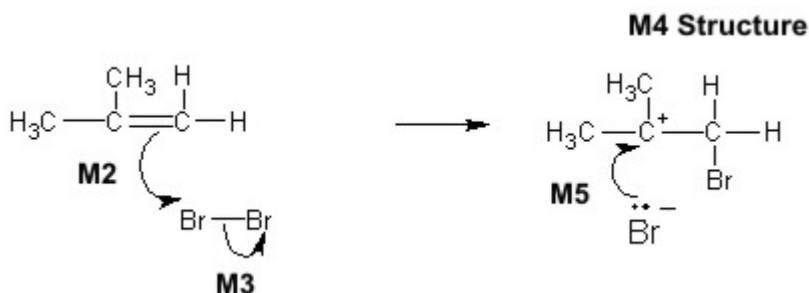


Penalise C_3H_7

Accept correct "sticks"

1

(b) **M1 Electrophilic addition**



M2 must show an arrow from the double bond towards the Br atom of the Br-Br molecule

M3 must show the breaking of the Br-Br bond.

M4 is for the structure of the tertiary carbocation with Br on the correct carbon atom.

M5 must show an arrow from the lone pair of electrons on the negatively charged bromide ion towards the positively charged carbon atom.

N.B. These are double-headed arrows

For M1, both words required.

For the mechanism

M2 Ignore partial negative charge on the double bond.

M3 Penalise partial charges on Br-Br bond if wrong way and penalise formal charges

Penalise once only in any part of the mechanism for a line and two dots to show a bond

Max any 3 of 4 marks for the mechanism for

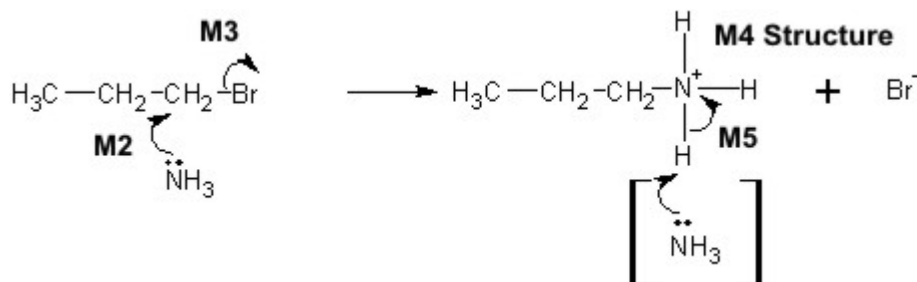
wrong organic reactant or wrong organic product (if shown) or primary carbocation.

If HBr is used, max 2 marks **for their mechanism**

Accept the correct use of "sticks"

5

(c) **M1 Nucleophilic substitution**



M2 must show an arrow from the lone pair of electrons on the nitrogen atom of an ammonia molecule to the C atom.

M3 must show the movement of a pair of electrons from the C-Br bond to the Br atom. **M3** is independent provided it is from their original molecule

M4 is for the structure of the alkylammonium ion, which could be a condensed formula. A positive charge must be shown on/or close to, the N atom.

M5 is for an arrow from the N-H bond to the N atom.

Award full marks for an S_N1 mechanism in which M2 is the attack of the ammonia on the intermediate carbocation.

N.B. These are double-headed arrows

For M1, both words required.

Penalise M2 if NH₃ is negatively charged.

Penalise M3 for formal charge on C or incorrect partial charges

The second mole of ammonia is not essential for M5; therefore ignore any species here.

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

*Max any 3 of 4 marks **for the mechanism** for wrong organic reactant (or wrong organic product if shown)*

Accept the correct use of “sticks”

5

[15]

8

(a) (i) Electron pair donor

OR

Species which uses a pair of electrons to form a co-ordinate/covalent bond.

Credit “lone pair” as alternative wording

Credit “electron pair donator”

1

(ii) Replacement of the halogen (atom) (by the nucleophile)

OR

The carbon-halogen bond/C-X breaks and a bond forms with the nucleophile or between the carbon and the nucleophile

They must describe the idea of substitution in a haloalkane.

Accept the idea that a nucleophile replaces the halogen which becomes a halide ion

Penalise reference to “halogen molecule” and penalise the idea that the haloalkane contains a halide

1

(iii) Splitting molecules using/by water

OR

breaking/splitting/dissociating (C_iVX) bond(s)/using/by water

NOT simply the reaction with water or simply the addition of water.

Ignore “compound”

1

- (iv) (Heat) energy/enthalpy required/needed/absorbed (at constant pressure) to break/split it/the (carbon-halogen) bond

OR

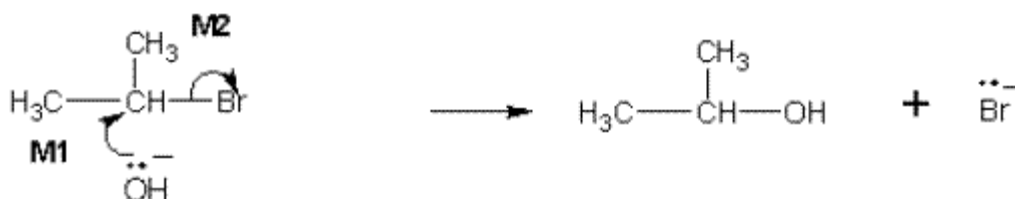
- (Heat) energy/enthalpy required/needed/absorbed (at constant pressure) for homolysis of the (C-X/the carbon-halogen) bond

Ignore bond formation

Ignore "average"

1

(b)



- M1** must show an arrow from the lone pair of electrons on the oxygen atom of the negatively charged hydroxide ion to the central C atom.

- M2** must show the movement of a pair of electrons from the C-Br bond to the Br atom. Mark M2 independently.

Award full marks for an S_N1 mechanism in which M1 is the attack of the hydroxide ion on the intermediate carbocation.

Penalise M1 if covalent KOH is used

Penalise M2 for formal charge on C or incorrect partial charges

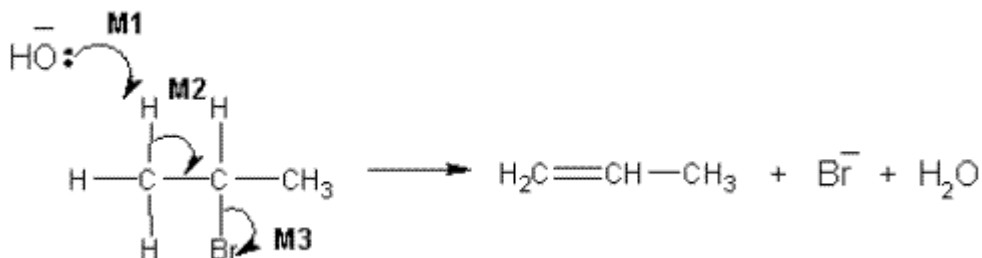
Penalise once only for a line and two dots to show a bond.

Max 1 mark for the wrong reactant

Accept the correct use of "sticks"

2

(c) (i)



- M1** must show an arrow from the lone pair on oxygen of a negatively charged hydroxide ion to the correct H atom

- M2** must show an arrow from the correct C-H bond to the C-C bond and should only be awarded if an attempt has been made at M1

M3 is independent provided it is from the original molecule

Award full marks for an E1 mechanism in which M2 is on the correct carbocation.

Penalise M1 if covalent KOH

Penalise M3 for formal charge on C or incorrect partial charges

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

Max 2 marks for wrong reactant

Accept the correct use of "sticks" for the molecule except for the C-H being attacked

3

- (ii) **M1** Stated that the spectrum has an absorption/absorbance/ peak in the range 1620 cm⁻¹ to 1680 (cm⁻¹) or specified correctly in this range from the spectrum

M2 depends on correct range or wavenumber being specified

M2 (Infrared absorption) due to C=C OR carbon-carbon double bond
QoL for correct M1 statement which includes both the word absorption (or alternative) and the correct range or wavenumber

Allow "peak" OR "dip" OR "spike" OR "trough"

OR "low transmittance" as alternatives for absorption.

For M2 it is not sufficient simply to state that an alkene has C=C

M2 could be on the spectrum

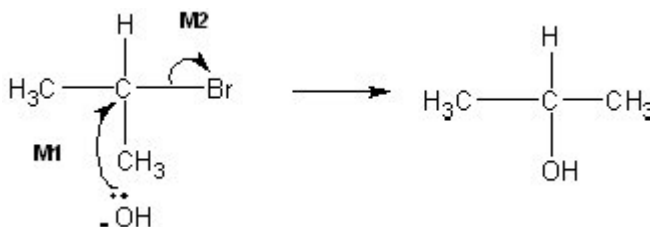
Ignore reference to other absorptions

2

[11]

9(a) (i) Nucleophilic substitution

1



2

M1 must show an arrow from the lone pair of electrons on the oxygen atom of the negatively charged hydroxide ion to the central C atom.

M2 must show the movement of a pair of electrons from the C-Br bond to the Br atom. Mark M2 independently.

Penalise M1 if covalent KOH is used

Penalise M2 for formal charge on C or incorrect partial charges

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

*Max 1 mark **for the mechanism** for the wrong reactant and/or "sticks"*

Ignore product

Award full marks for an S_N1 mechanism in which M1 is the attack of the hydroxide ion on the intermediate carbocation.

(ii) 2-bromopropane ONLY

1

(iii) Polar C-Br **OR** polar carbon-bromine bond **OR** dipole on C-Br
OR δ⁺ (δ⁻)C atom of carbon-bromine bond is δ⁺/electron deficient **OR** C-Br

(Credit carbon-halogen bond as an alternative to carbon-bromine bond)

It must be clear that the discussion is about the carbon atom of the C-Br bond. NOT just reference to a polar molecule.

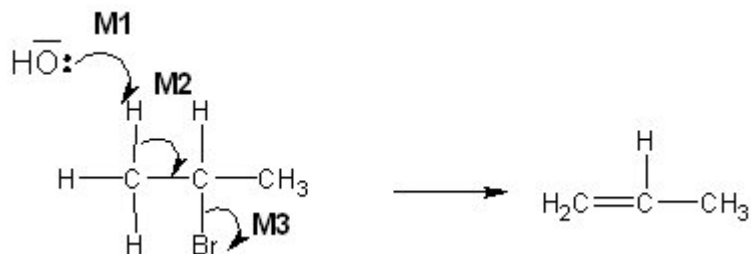
Ignore X for halogen

1

(b) Elimination

Credit "base elimination" but NOT "nucleophilic elimination"
No other prefix.

1



3

M1 must show an arrow from the lone pair on oxygen of a negatively charged hydroxide ion to the correct H atom

M2 must show an arrow from the correct C-H bond to the C-C bond and should only be awarded if an attempt has been made at M1

M3 is independent.

Mechanism

Penalise M1 if covalent KOH

Penalise M3 for formal charge on C or incorrect partial charges

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

Max 2 marks **for the mechanism** for wrong reactant and/or "sticks"

Ignore product

Award full marks for an E1 mechanism in which M2 is on the correct carbocation.

(c) *Any one condition from this list to favour elimination;*

Apply the list principle

- alcohol(ic)/ethanol(ic) (solvent)
- high concentration of KOH/alkali/hydroxide **OR** concentrated KOH/hydroxide
Ignore "aqueous"
- high temperature or hot or heat under reflux or $T = 78$ to 100°C
Ignore "excess"

1

(d) (i) Addition (polymerisation) ONLY

Penalise "additional"

1

- (ii) But-2-ene ONLY (hyphens not essential)
 Ignore references to *cis* and *trans* or
E/Z
 Ignore butane

1

[12]

10

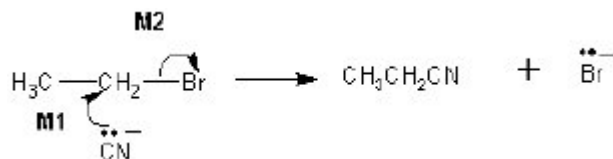
- (a) Electron pair donor
OR

Species which uses a pair of electrons
 to form a co-ordinate / covalent bond.

QoL
 Credit "lone pair" as alternative wording

1

- (b)



- M1** Must show an arrow from the lone pair of electrons
 on the carbon atom of the negatively charged
 cyanide ion to the central C atom.
- M2** Must show the movement of a pair of electrons from
 the C-Br bond to the Br atom. Mark M2 independently.

Award full marks for an S_N1 mechanism in which M1 is the
 attack of the cyanide ion on the intermediate carbocation.

Penalise M1 if covalent KCN is used
Penalise M2 for formal charge on C or incorrect partial charges
Penalise once only for a line and two dots to show a bond.
Max 1 mark for the wrong reactant or "sticks"

2

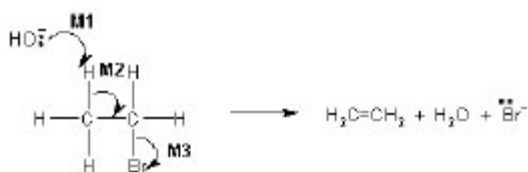
- (c) Ethylamine / $\text{CH}_3\text{CH}_2\text{NH}_2$ is a nucleophile
OR
Ethylamine could react further
OR
Ethylamine could make secondary / tertiary amines
OR
To make reaction with ammonia more likely
OR
To minimise further substitution
OR
The idea of releasing free amine from the salt
OR
The idea of removing a proton from the intermediate
alkylammonium ion
OR
The idea that ammonia acts both initially as a nucleophile and
then as a base

*Do not credit a simple reference to the equation or the mechanism
requiring two moles of ammonia.*

1

(d) **Elimination**

Credit "base elimination" but NOT "nucleophilic elimination"
No other prefix.



1

M1 Must show an arrow from the lone pair on oxygen of a negatively charged hydroxide ion to the correct H atom

M2 Must show an arrow from the correct C-H bond to the C-C bond and should only be awarded if an attempt has been made at M1

M3 Is independent.

Award full marks for an E1 mechanism in which M2 is on the correct carbocation.

Mechanism

Penalise M1 if covalent KOH

Penalise M3 for formal charge on C or incorrect partial charges

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

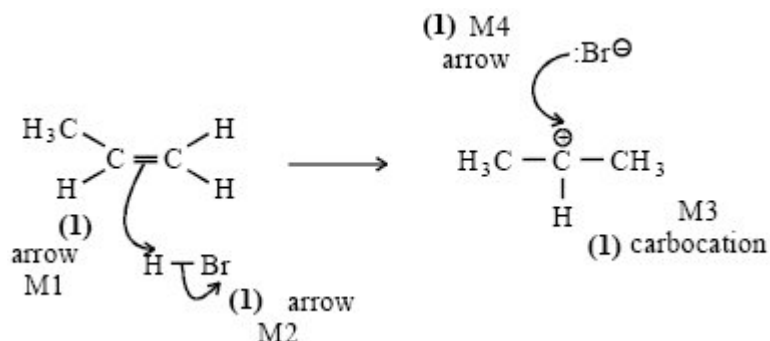
Max 2 marks **for the mechanism** for wrong reactant or "sticks"

3

[8]

11

(a) (i)



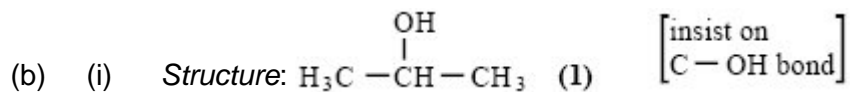
If wrong carbocation, lose structure mark
If wrong alkene, lose structure mark
Can still score ¾ i.e. penalise M3
Penalise M2 if polarity included incorrectly
no bond between H and Br
bond is shown as $\overset{\cdot\cdot}{\text{H}}-\text{Br}$ or $\text{H}-\overset{\cdot\cdot}{\text{Br}}$

4

- (ii) \oplus
 $\text{CH}_3\text{CH}_2\text{CH}_2$
 credit secondary carbocation here if primary carbocation has been used in (i)

Ignore attack on this carbocation by $\ddot{\text{Br}}^-$

1



1

Name: propan-2-ol

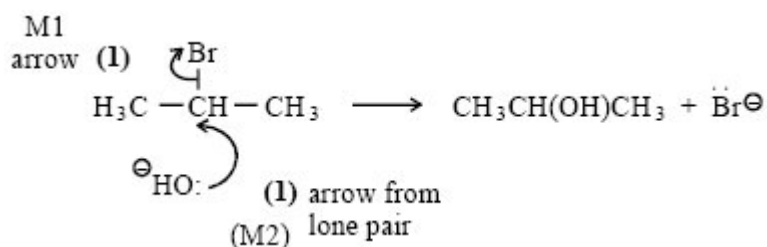
Not 2-hydroxypropane

1

- (ii) Name of mechanism: nucleophilic substitution (both words)
 (NOT $\text{S}_{\text{N}}1$ or $\text{S}_{\text{N}}2$)

1

Mechanism:



penalise incorrect polarity on C-Br (M1)

Credit the arrows even if incorrect haloalkane

If $\text{S}_{\text{N}}1$, both marks possible

2

- (c) (i) elimination

1

- (ii) base

OR proton acceptor

NOT nucleophile

1

[12]

12

[1]

(a) (base) elimination

(penalise other words before 'elimination' e.g. nucleophilic)

1

M1: curly arrow from lone pair of electrons on oxygen of hydroxide ion

(insist on a lone pair of electrons on the oxygen atom and a negative charge, but only credit this mark if the attack is to a correct H atom)

1

M2: curly arrow from the middle of the C-H bond to the middle of the C-C bond

(only credit this mark if the arrow originates from the correct C-H bond and if an attempt has been made at M1)

1

M3: curly arrow from the middle of the C-Br bond towards/alongside the Br atom

(credit M3 independently unless the bond breaking is contradicted by an additional arrow)

(penalise curly arrow if the C-Br has a formal positive charge)

(credit full marks for an E1 mechanism, with M2 awarded for a correct curly arrow on the correct carbocation)

(award a maximum of two marks for either an incorrect haloalkane or an incorrect organic product)

(maximum 2 marks for use of 'sticks' for the haloalkane, unless RE from 2(b), when credit can be given)

(b) (i) **M1:** compounds with the same structural formula

1

M2: but the bonds/groups/atoms have different spatial arrangements or orientation or configuration/are arranged differently in space/3D

(ignore reference to the same molecular formula for M1)

1

(ii) **M1:** correct structural representation for cis-but-2-ene and its name or its identification as the cis isomer

1

M2: correct structural representation for trans-but-2-ene and its name or its identification as the trans isomer

(accept representations which are 90° to linear)

(award one mark for two correct structures but either wrong/no names)

(maximum 1 mark for an incorrect alkene)

1

(iii) geometric(al) or cis-trans

1

(c) nucleophile or electron pair donor
(penalise 'base')

1

(d) $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{Br} + 2\text{NH}_3 \rightarrow \text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{NH}_2 + \text{NH}_4\text{Br}$
(M1 correct product)
(M2 balanced equation using 2NH_3 and leading to NH_4Br)
(penalise M1 for use of $\text{C}_4\text{H}_9\text{NH}_2$ or for incorrect haloalkane, but allow consequent correct balancing of equation with 2 moles of ammonia)

2

(1-)butylamine
(credit 1-aminobutane and butyl-1-amine)
(award QoL mark for correct spelling)

1

[13]

14

(a) 2-bromobutane;

1

(b) Elimination;
(penalise "nucleophilic" OR "electrophilic" before the word "elimination")

1

M1: curly arrow from lone pair on oxygen of hydroxide ion to H atom on correct C-H adjacent to C-Br;
(penalise M1 if KOH shown as covalent with an arrow breaking the bond)

1

M2: curly arrow from single bond of adjacent C-H to adjacent single bond C-C;
(only credit M2 if M1 is being attempted to correct H atom)

1

M3: curly arrow from C-Br bond to side of Br atom;
(credit M3 independently unless arrows contradict)
(Credit possible repeat error from 2(c)(iii) for M3)
(If the wrong haloalkane is used OR but-1-ene is produced, award MAX. 2 marks for the mechanism)
(If E1 mechanism is used, give full credit in which M1 and M2 are for correct curly arrows on the correct carbocation)

- (c) (i) (structural) isomers/hydrocarbons/compounds/they have the same molecular formula, but different structural formulas/different structures; 1
(penalise statements which are not expressed in good English and which do not refer clearly to structural isomers i.e. plural)
(penalise statements which refer to “different (spatial) arrangements”)
(credit “different displayed formulas”)
(Q of L mark)

(ii) Correct structure for but-1-ene;

1

[7]

^A
15

[1]

16

- (a) M1 curly arrow from lone pair on oxygen of hydroxide ion to H atom on C-H adjacent to C-Br

1

M2 curly arrow from single bond of adjacent C-H to adjacent single bond C-C

(only credit M2 if M1 is being attempted to correct H atom)

1

M3 curly arrow from C-Br bond to side of Br atom

(credit M3 independently)

1

- (b) M1 credit a correct structure for either geometrical E-Z isomer and its designation as either *cis* or *trans*.
OR credit two correct geometrical E-Z isomer structures (ignore the names)
OR credit two correct names for *cis* pent-2-ene and *trans* pent-2-ene (ignore the structures)

1

M2 credit a second mark if all four parts of the required structures and names are correct.

(credit “linear” structures)

(insist on the alkyl groups being attached clearly by C-C bonds)

1

- (c) (i) M1 curly arrow from middle of C = C bond to H atom on H-Br
(penalise M1 if partial negative charge or formal positive charge on H)
(penalise M1 if pent-2-ene is used) 1
- M2 curly arrow from H-Br bond to side of Br atom 1
- M3 correct structure for correct secondary carbocation 1
- M4 curly arrow from lone pair on bromide ion to the positive carbon of carbocation, ensuring that bromide ion has a negative charge.
(with the exception of pent-2-ene, if the wrong alkene is used, only penalise the structure M3)
(penalise the use of two dots in addition to a covalent bond, once only) 1
- (ii) 1-bromopentane 1
- (iii) M1 2-bromopentane is formed *via* the secondary (or 2°) carbocation 1
- OR 1-bromopentane is formed *via* the primary (or 1°) carbocation
 M2 a secondary carbocation is more stable than a primary carbocation -
 award this mark only if the quality of language justifies the award.
(the argument must involve clear statements about carbocations) 1

[12]

18

- (a) Reaction 2: NaOH OR KOH **(1)** M1 alcohol (ic) OR ethanol (ic)**(1)** M2
ignore heat

Condition mark linked to correct reagent but award M2 if OH⁻ or base or alkali mentioned

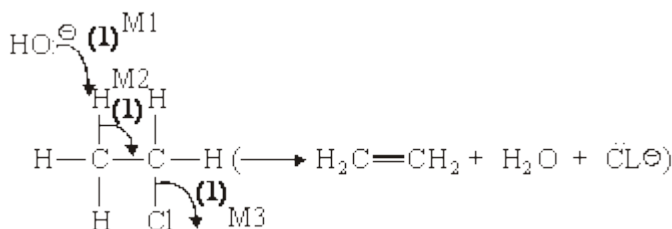
Reaction 3: concentrated H₂SO₄ OR H₃PO₄ M1 **(1)** heat **(1)** M2
OR 150°C - 200°C

Condition mark linked to correct reagent but award M2 if H₂SO₄ or H₃PO₄, but not concentrated

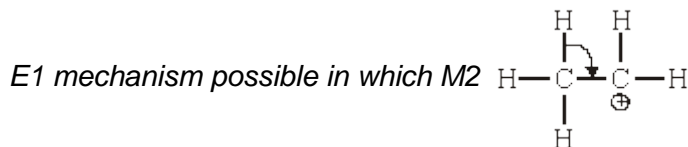
Penalise reagent and condition if dilute H₂SO₄ / H₃PO₄

4

- (b) Mechanism:



Award M3 (C—Cl) independently
M1 and M2 must be to / from correct places



Name: of mechanism = elimination **(1)**

NOT dehydrohalogenation

Ignore "base" OR "nucleophilic" before elimination

Reason: Reaction 2 has (very) low yield **(1)**

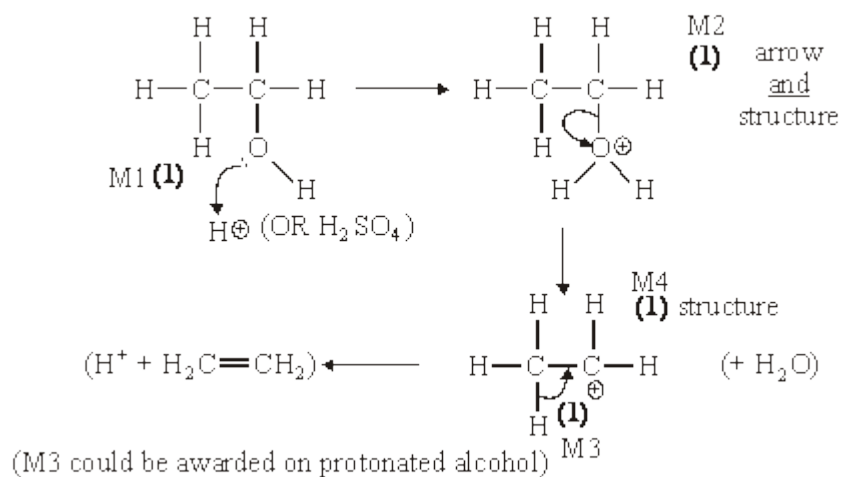
5

QoL OR chloroethane has to be made (from ethane)

OR chloroethane is expensive

OR chloroethane is not readily available

(c) Mechanism:



Name of mechanism = elimination (1)

NOT dehydration alone

Reason: Ethanol could come from (fermentation of) renewable

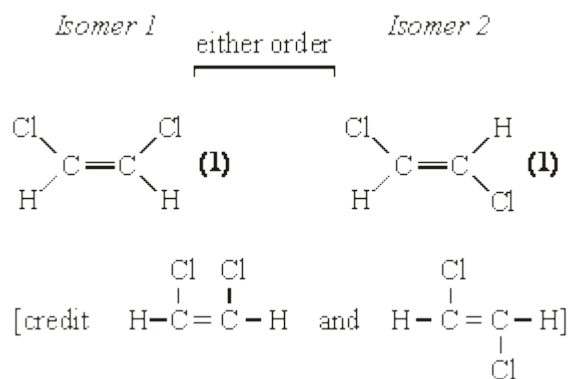
QoL sugars / glucose / carbohydrates / sources (1)

6

[15]

19

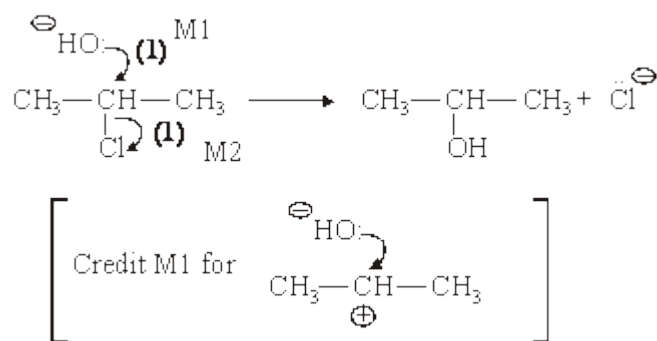
(a) (i)



(ii) restricted rotation OR no rotation OR cannot rotate (1)

3

(b) (i) Mechanism:



M1 and M2 independent

Curly arrows must be from a bond or a lone pair

Do not penalise sticks

Penalise M1 if Na-OH precedes (penalise this once)

Penalise incorrect $\delta+$ $\delta-$ for M2

Penalise + on C atom for M2

Only allow M1 for incorrect haloalkane

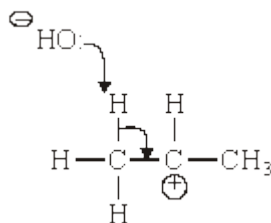
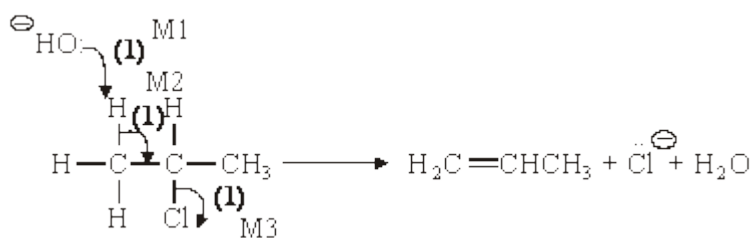
Role of the hydroxide ion: nucleophile (1)

electron pair donor

lone pair donor

NOT nucleophilic substitution

(ii) Mechanism:



Only allow M1 and M2 for incorrect haloalkane unless RE on (i)

+ charge on H on molecule, penalise M1

M3 independent

M2 must be to correct C-C

M1 must be correct H atom

Credit M1 and M2 via carbocation mechanism

No marks after any attack of C[⊕] by OH⁻

Role of the hydroxide ion: base **(1)**

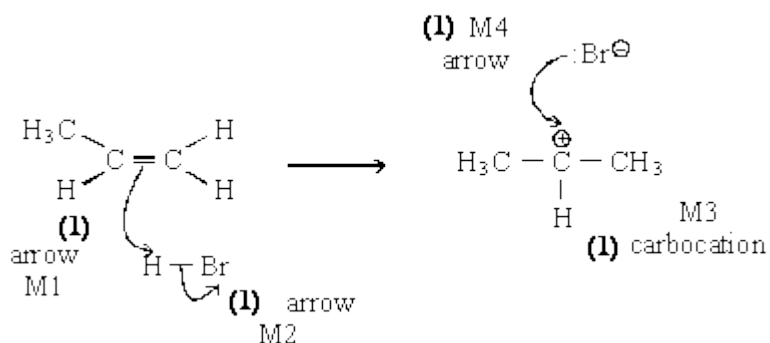
proton acceptor

accepts H⁺

7

[10]

(a) (i)



If wrong carbocation, lose structure mark

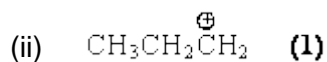
If wrong alkene, lose structure mark

Can still score $\frac{3}{4}$ i.e. penalise M3

Penalise M2 if polarity included incorrectly

no bond between H and Br

bond is shown as $\overset{\cdot\cdot}{\text{H}}-\text{Br}$ or $\text{H}-\overset{\cdot\cdot}{\text{Br}}$

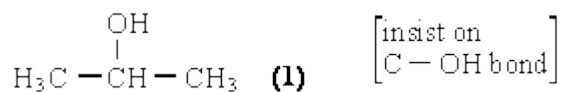


credit secondary carbocation here if primary carbocation has been used in (i)

Ignore attack on this carbocation by $:\text{Br}^-$

5

(b) (i) Structure:



No credit for propan-1-ol even when named correctly

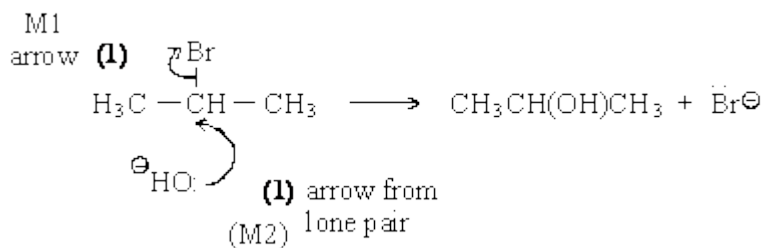
Credit propane-2-ol

Name: propan-2-ol (1)

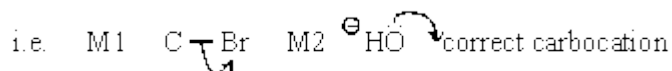
Not 2-hydroxypropane

- (ii) *Name of mechanism: nucleophilic substitution (1) (both words)*
(NOT S_N1 or S_N2)

Mechanism:



penalise incorrect polarity on C-Br (M1)
Credit the arrows even if incorrect haloalkane
If S_N1, both marks possible



5

- (c) (i) **elimination (1)**
Ignore nucleophilic elimination
Penalise electrophilic elimination

- (ii) **base (1)**
OR proton acceptor
NOT nucleophile (base)

2

[12]

21

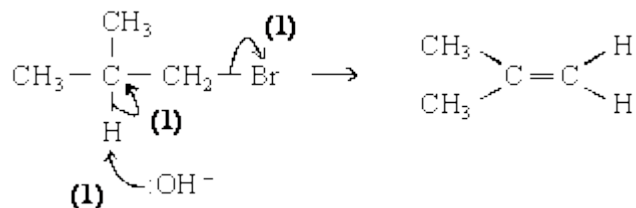
- (a) **Identity of X; 2-methylpropene (1)**
Absorption at 1650 cm⁻¹ indicates an alkene present (1)
OR a chemical answer e.g. Br₂ (aq) brown to colourless

2

- (b) Reagents
 Step 1 KOH (allow NaOH) (1) alcoholic (1) warm (1)
Only allow solvent and warm if reagent correct

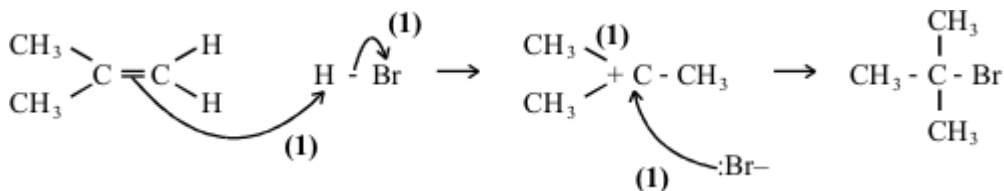
Step 2 HBr (1)

Mechanism: A → X



Or a carbocation mechanism

Mechanism X → B



11

- (c) A gives three peaks (1)
 B gives one peak (1)
Allow one for "A has more peaks than B" when no number of peaks is given

2

[15]

22

[1]

23

- (a) Alcohol: Reaction = Substitution (/ hydrolysis) (1)
Ignore reference to nucleophilic, but electrophilic give zero
- Alcohol: Role = nucleophile (/ lone pair donor) (1)
- Alkene: reaction = elimination (1)
Ignore ref to nucleophilic or electrophilic
- Alkene: base (/ proton acceptor) (1)
*If no indication of order in (a) assume as in question.
 If order is wrong can still score 'role' mark.*

4

(b) Alcohol: Role = butan-2-ol **(1)**

Not 2-hydroxybutane or but-2-ol

Appropriate structure for CH₃CH(OH)CH₂CH₃ **(1)**

Brackets not essential

S_N2 version

S_N1 version

δ^+ δ^-
C—Br bond is polar

C—Br bond is polar **(1)**

Lone pair of OH⁻

C—Br bond breaks **(1)**

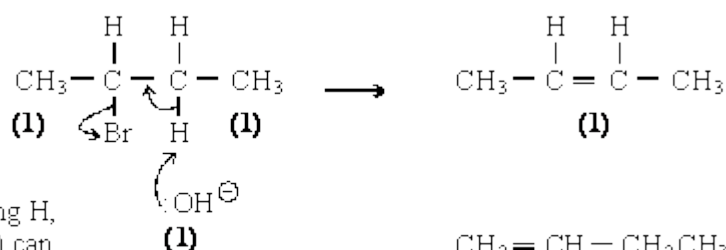
Attacks the C^{δ+}

forming carbocation / carbonium ion **(1)**

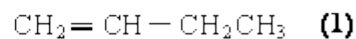
M1 can be scored from a diagram, M2 and M3 from written explanation only

5

(c)



if OH⁻ attacks wrong H,
(ie. not on C₁ or C₃) can
only score C—Br mark



If but-2-ene not given here it may be obtained from cis / trans isomer

H lost from different carbon atoms (1)

H removes from C¹ and C³ to give two isomers (1)

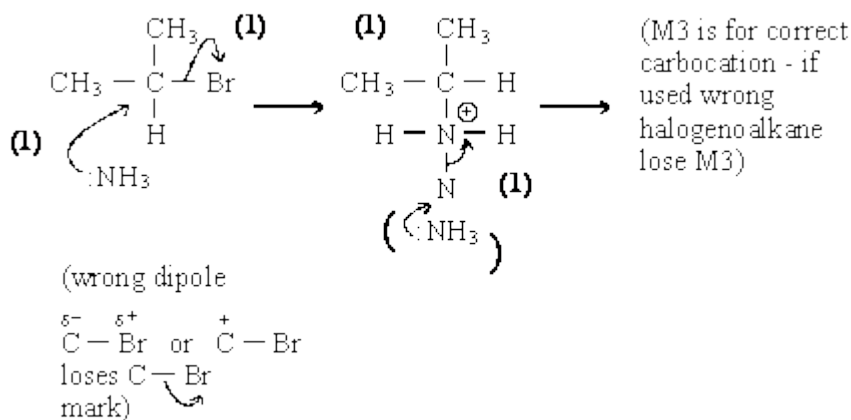
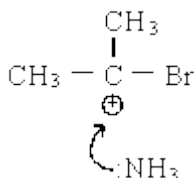
Draws clear Cis and trans isomers for but-2-ene

Can score these marks from a diagram

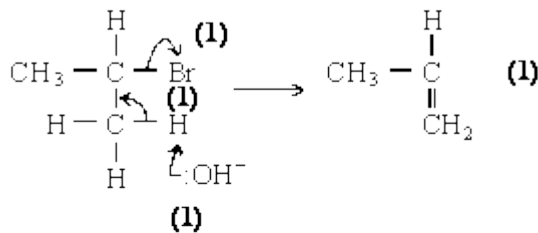


8

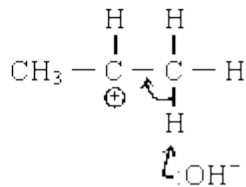
[17]

24(a) *Name of mechanism: nucleophilic substitution (1)**Mechanism:**Marks S_N1 using same points**∴ M2 requires*

5

(b) *Role of potassium hydroxide: Base (1)**Mechanism:*

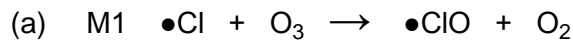
Mark E1 using same points

∴ M2/M3

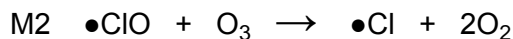
5

[10]

25



1



1

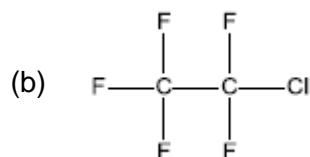
M1 and M2 could be in either order

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

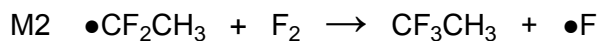
1

- (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

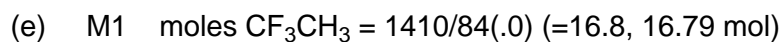


1

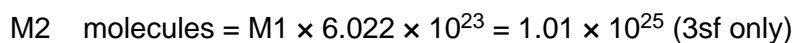
M1 and M2 could be in either order

Credit the dot anywhere on the radical

Penalise absence of dot once only



1



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

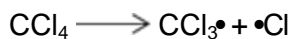
1

[9]

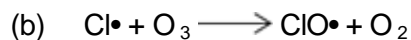
26

- (a) UV light

1



1



1



1



$$\text{Moles freon} = 1.78 \times 10^{-4} \times 10^3 / 104.5 = 1.70 \times 10^{-3}$$

1

$$\text{Number of molecules} = 1.70 \times 10^{-3} \times 6.02 \times 10^{23} = 1.02 \times 10^{21}$$

1

$$\begin{aligned} \text{Molecules in } 500 \text{ cm}^3 &= (1.02 \times 10^{21} \times 500 \times 10^{-6}) / 100 \\ &= 5.10 \times 10^{15} \end{aligned}$$

Allow answer in the range 5.10 – 5.13×10^{15}

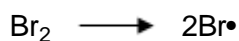
Answer must be given to this precision

1

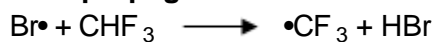
[7]

27

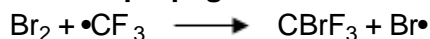
(a) (i) **Initiation**



First propagation



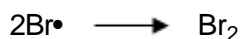
Second propagation



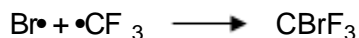
Termination



OR



OR



Penalise absence of dot once only

Credit the dot anywhere on the radical

4

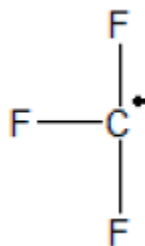
(ii) Ultra-violet / uv / sunlight

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*

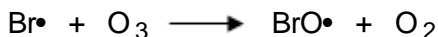
Give credit for an answer that suggests that the UV frequency / energy may favour C–Br bond breakage rather than C–Cl bond breakage

Ignore correct references either to size, polarity or electronegativity

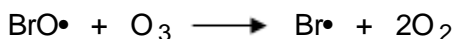
Credit correct answers that refer to, for example “the bond between carbon and bromine requires less energy to break than the bond between carbon and chlorine”

1

(iii) **M1**



M2



***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

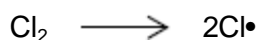
M3 One of the following

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

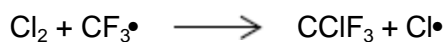
[10]

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

Penalise absence of dot once only.

M2 First propagation

Penalise + or - charges every time.

M3 Second propagation

Credit $\text{CF}_3\cdot$ with the radical dot above / below / to either side.

M4 Termination (must make C_2F_6)

Mark independently.

4

(ii) ultra-violet / uv / sun light

OR (very) high temperature**OR** $500\text{ }^\circ\text{C} \leq T \leq 1000\text{ }^\circ\text{C}$ **OR** $773\text{ K} \leq T \leq 1273\text{ K}$

1

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

Not 'chlorine' alone.

Credit 'Cl' alone on this occasion.

1

(ii) $2\text{O}_3 \longrightarrow 3\text{O}_2$

Or multiples.

Ignore state symbols.

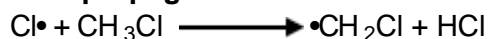
If the correct answer is on the line OR clearly identified below some working, then ignore any working.

1

[7]

29(a) **Initiation**

Penalise absence of dot once only.

First propagation

Credit the dot anywhere on the radical.

Second propagation**Termination (must make 1,2-dichloroethane)**

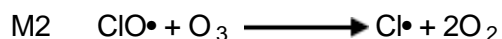
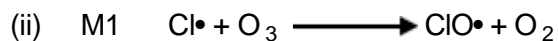
Penalise C₂H₄Cl₂

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]**30**(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

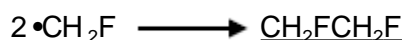
Second propagation



Accept dot anywhere on CH₂F radical

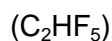
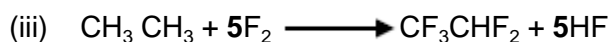
Mark independently

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"

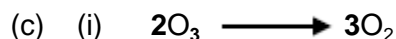
*Penalise "flouro" and "floro", since **QoL***

OR

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

Ignore commas and hyphens

1

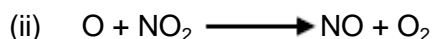


ONLY this equation or a multiple

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]

31

- (a) (i) chlorotrifluoromethane
Spelling must be correct but do not penalise "flouro"
Ignore use of 1- 1
- (ii) $\text{CF}_3\bullet$
May be drawn out with dot on C
OR if as shown dot may be anywhere 1
- (iii) An unpaired/non-bonded/unbonded/free/a single/one/lone
electron
NOT "bonded electron" and NOT "paired electron"
NOT "pair of electrons"
NOT "electron s"
Ignore "(free) radical" 1
- (b) **M1** $\text{Cl}\bullet + \text{O}_3 \rightarrow \text{ClO}\bullet + \text{O}_2$
M2 $\text{ClO}\bullet + \text{O}_3 \rightarrow 2\text{O}_2 + \text{Cl}\bullet$
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

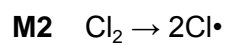
[9]

32

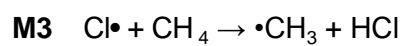
(a) **M1** (Free-) **radical substitution**

Both words needed

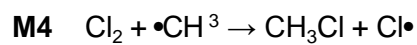
1



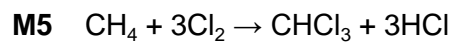
1



1

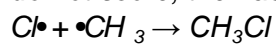


1



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



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.
- For M5 accept Cl• on both sides of the equation* 1
- M6** Stated that the role of the Cl• / chlorine atom is to find an alternative route **OR** lower E_a / activation energy 1

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

OR

Desflurane does not contain C–Cl bonds / Cl

OR

Desflurane contains C–F / F as the only halogen

Mark independently.

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

1

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

OR

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

1

[13]