Organic Chemistry
Grade 12 P 2

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Organic Chemistry

- Study of structure, properties and reactions of Carbon and Hydrogen.
- Hydrocarbons are compounds which contain carbon and hydrogen.
- Organic molecules are molecules which contain carbon atoms.

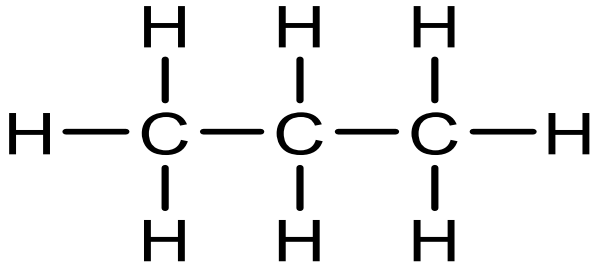
- Molecular formulae

  example: Propane

  C_3H_8

- Structural formulae

  example: Propane



- Condensed structural formulae

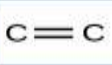
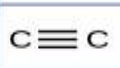
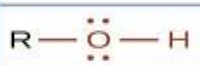
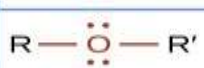
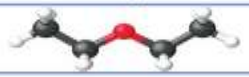
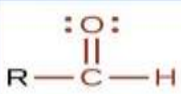
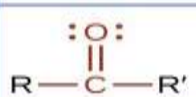
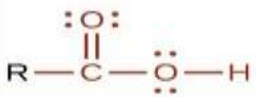
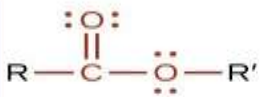
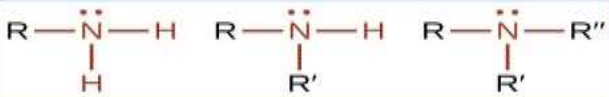
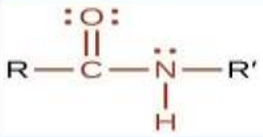
  example: Propane

  $CH_3CH_2CH_3$

- Functional group: A functional group will undergo the same chemical reaction regardless of the size of the molecule it is part of.

- Homologus series: A family of molecules which have the same functional group but different lengths of carbon chains. They can be represented by a general formula eg: C_nH_{2n+2} (alkanes)

Functional groups

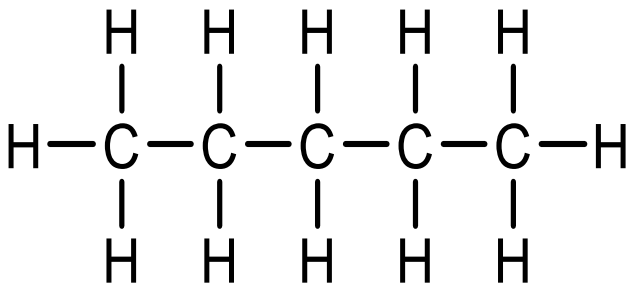
Compound Name	Structure of Compound and Functional Group (red)	Example	
		Formula	Name
alkene		C_2H_4 	ethene
alkyne		C_2H_2 	ethyne
alcohol		CH_3CH_2OH 	ethanol
ether		$(C_2H_5)_2O$ 	diethyl ether
aldehyde		CH_3CHO 	ethanal
ketone		$CH_3COCH_2CH_3$ 	methyl ethyl ketone
carboxylic acid		CH_3COOH 	acetic acid
ester		$CH_3CO_2CH_2CH_3$ 	ethyl acetate
amine		$C_2H_5NH_2$ 	ethylamine
amide		CH_3CONH_2 	acetamide

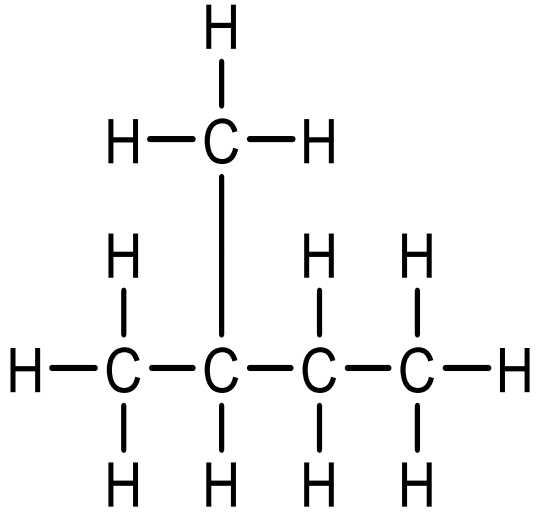
IUPAC

- IUPAC uses three system to naming a compound: parent, prefix and suffix.
- Parent: where and what functional groups.
- Prefix: number of carbon atoms.
- Suffix: homologus series.

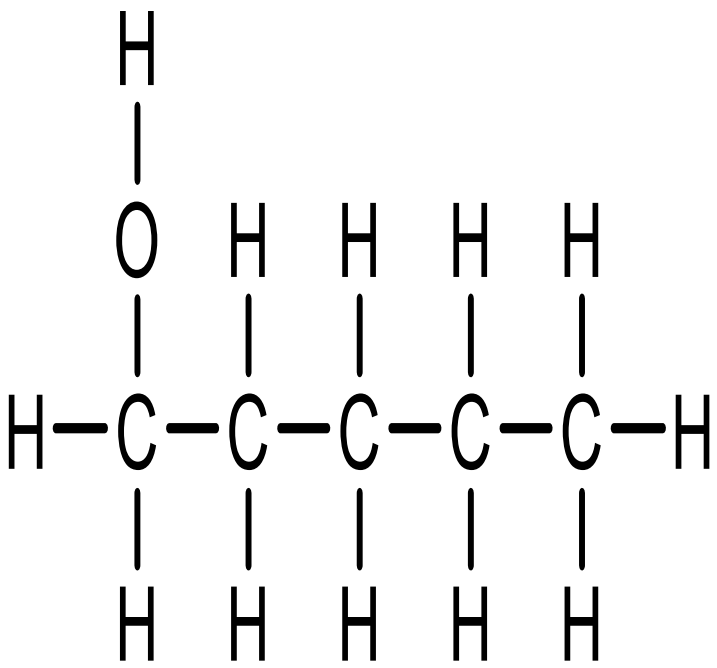
Isomerism

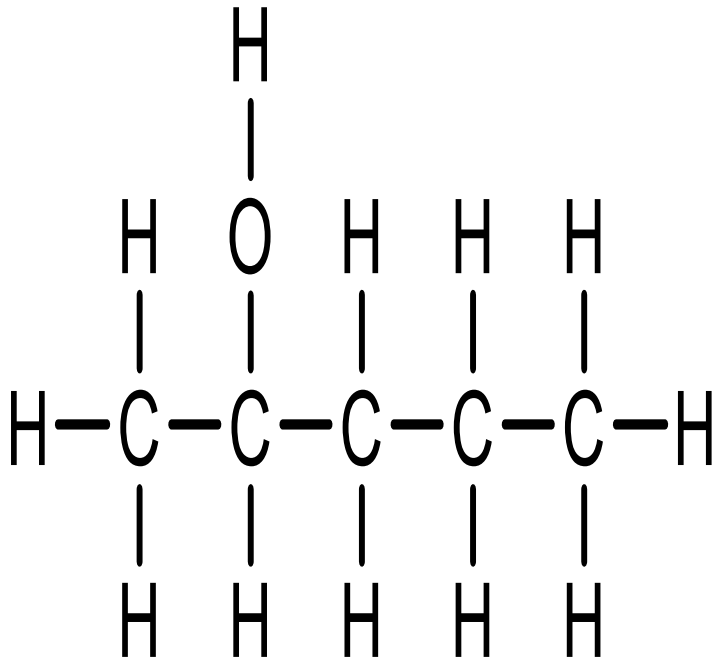
- Isomers are compounds with the same molecular formula but different structural formulae.
- Three types of isomers:
  - Chain isomers:



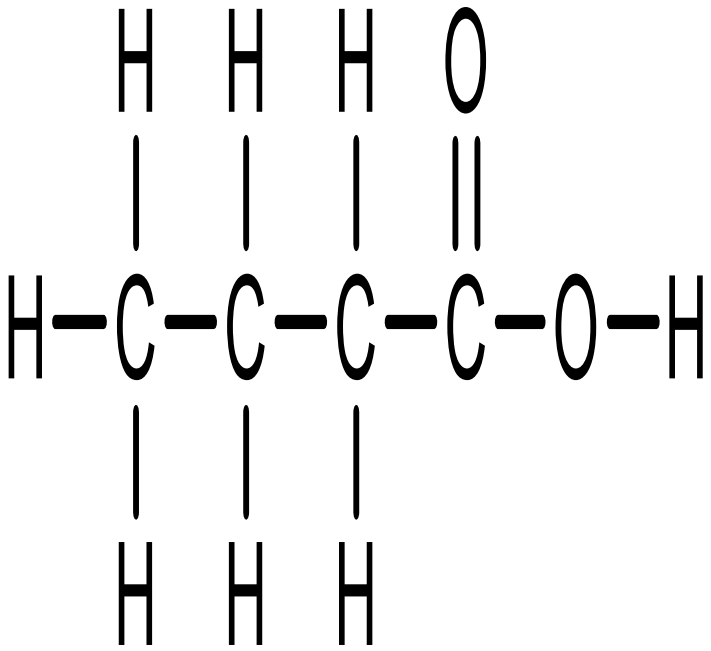


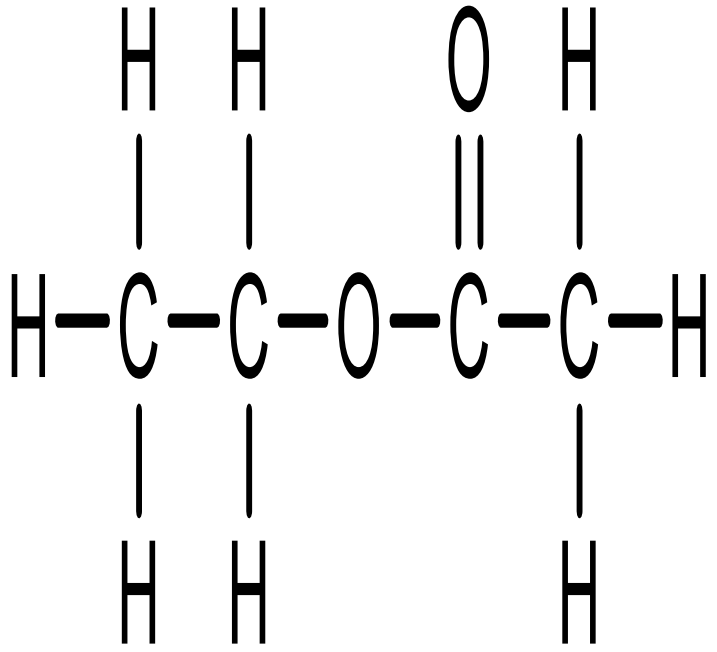
- Positional isomers





- Functional isomers





Functional groups and intermolecular forces

- Weak van der waals forces (dispersion or London forces) act between non-polar molecules (alkanes,alkenes, and alkynes).
- Stronger van der waals forces (dipole-dipole interaction) act between polar molecules (aldehydes,ketones, and esters).
- Strong Hydrogen bonds exist between a hydrogen on one molecule and an oxygen on another molecule (alcohol and carboxylic acids).

Chain length and branched chains

- Melting and boiling points increase with an increase in molecular mass.
- Straight chain molecules have higher melting points than branched-chained molecules with the same number of C atoms.

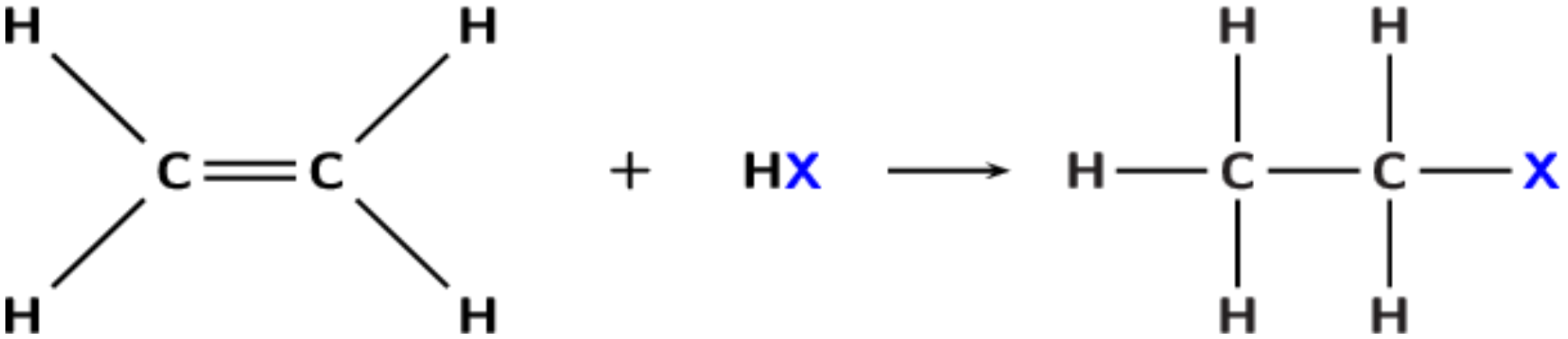
Formula	Name	Molar Mass	Boiling Point (°C)
CH_4	methane	16	–164
HOH	water	18	100
C_2H_6	ethane	30	–89
CH_3OH	methanol	32	65
C_3H_8	propane	44	–42
CH_3CH_2OH	ethanol	46	78
C_4H_{10}	butane	58	–1
$CH_3CH_2CH_2OH$	1-propanol	60	97

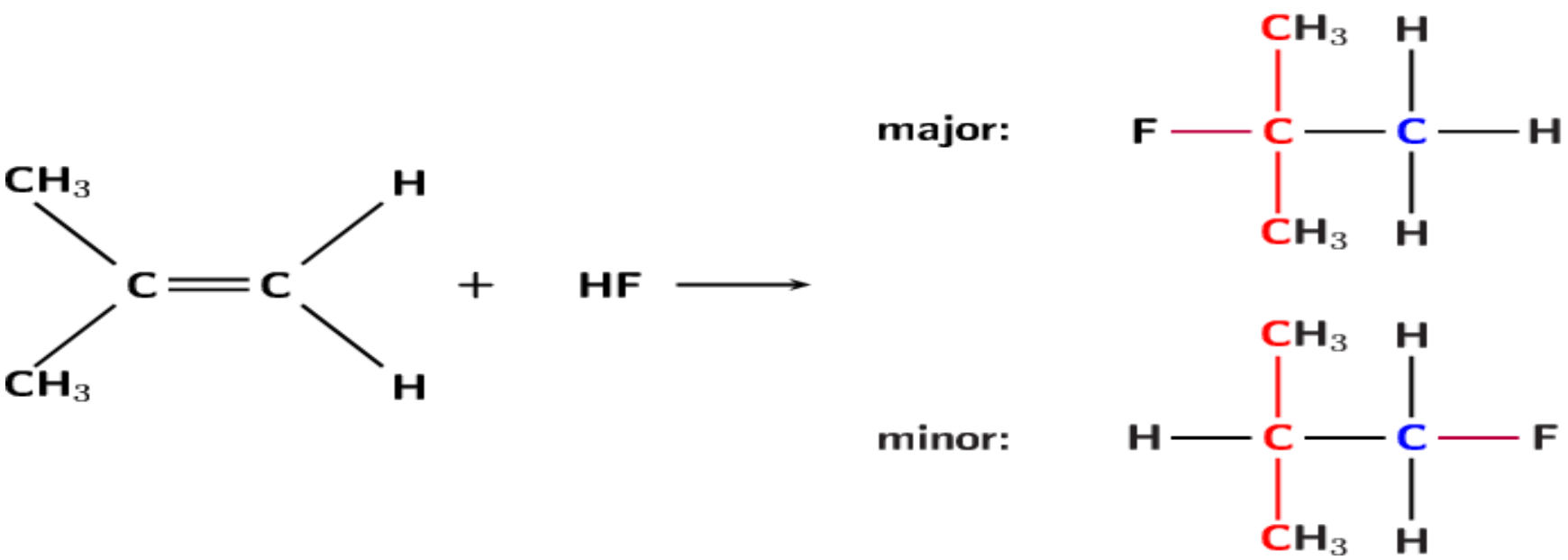
Addition reactions

Hydrohalogenation

Hydrohalogenation involves the addition of a hydrogen atom and a halogen atom to an unsaturated compound (containing a carbon-carbon double bond). An example is given; X can be fluorine (F), chlorine (Cl), bromine (Br) or iodine (I).

Addition reactions Continued,



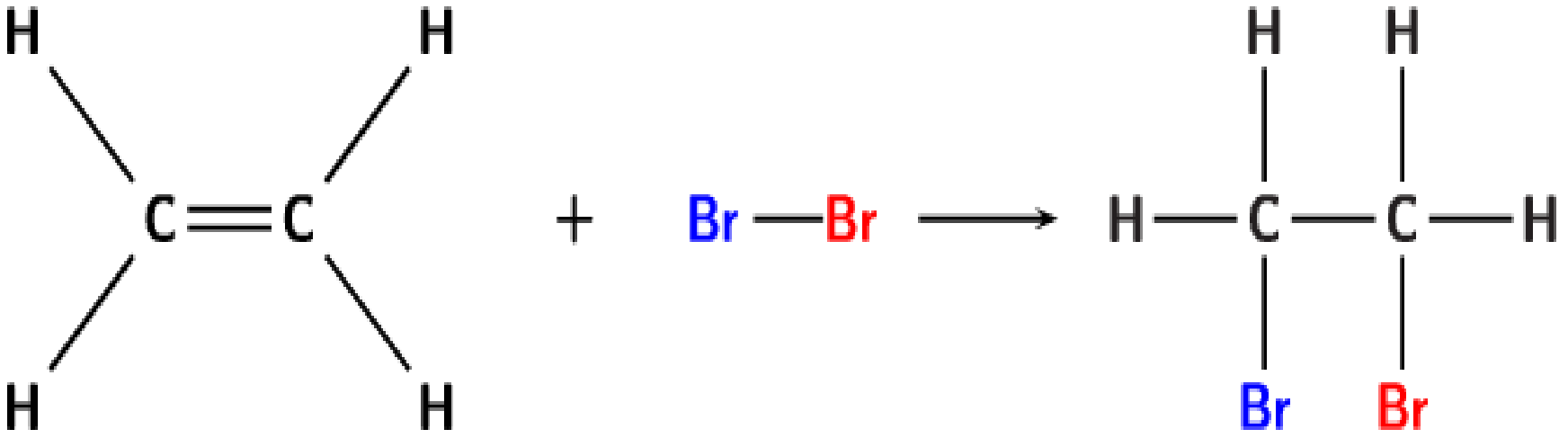


Addition reactions Continued,

- Reaction conditions: No water needed, the C atom bonds to the (secondary & tertiary) C atom that is highly substituted, while the H atom bonds to the (primary) C atom with more H atoms.
- Makovnikov's rule is obeyed.

Halogenation

- Halogenation is very similar to hydrohalogenation but a diatomic halogen molecule is added across the double bond. An example is given below.

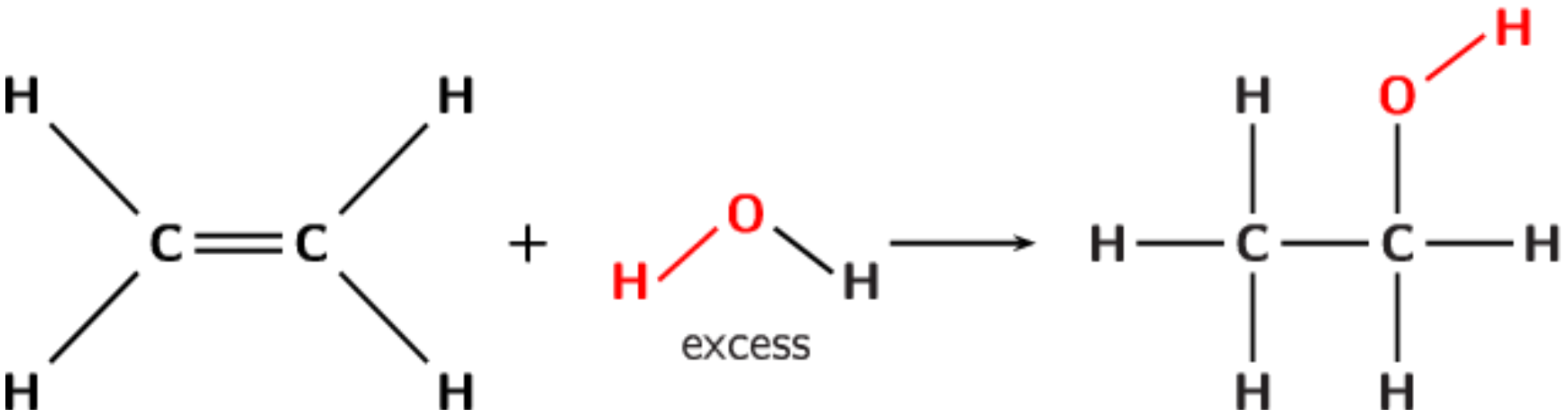


Halogenation continued,

- Halogenation reaction conditions: Reaction is spontaneous since alkenes are strong nucleophiles, while Br is a also a strong electrophile.

Hydration

- A hydration reaction involves the addition of water (H_2O) to an unsaturated compound. This is one way of preparing an alcohol from the corresponding alkene

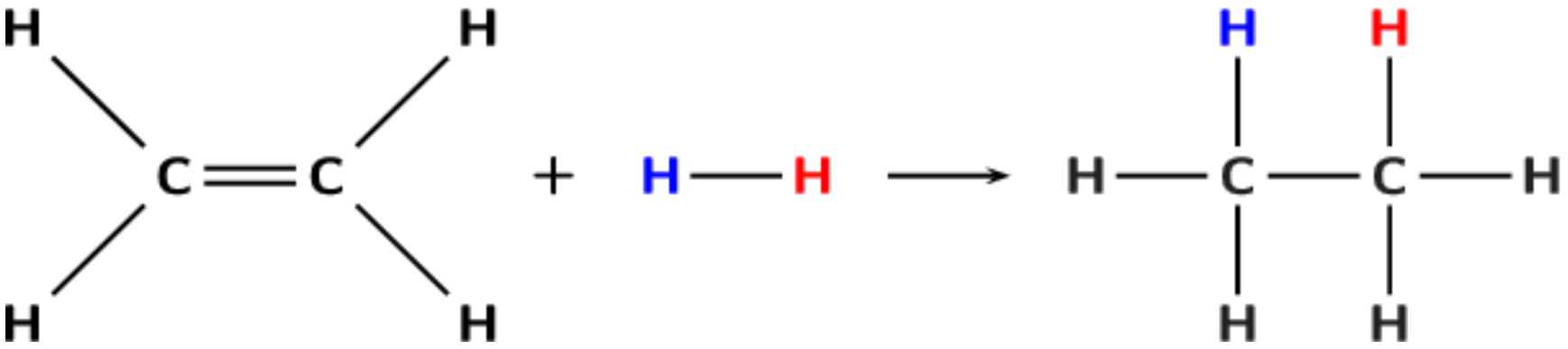


Hydration continued,

- Hydration reaction conditions: H_2O must be in excess. Use dilute H_2SO_4, HCl, or HPO_3 to catalize the reaction. The H attaches to the (primary) C that has more H, while the OH attaches to the more substituted (secondary & Tertiary) C atom.

Hydrogenation

- Hydrogenation involves adding hydrogen (H_2) to an alkene. During hydrogenation the double bond is broken (as with hydrohalogenation and halogenation) and more hydrogen atoms are added to the molecule. A specific example is shown below

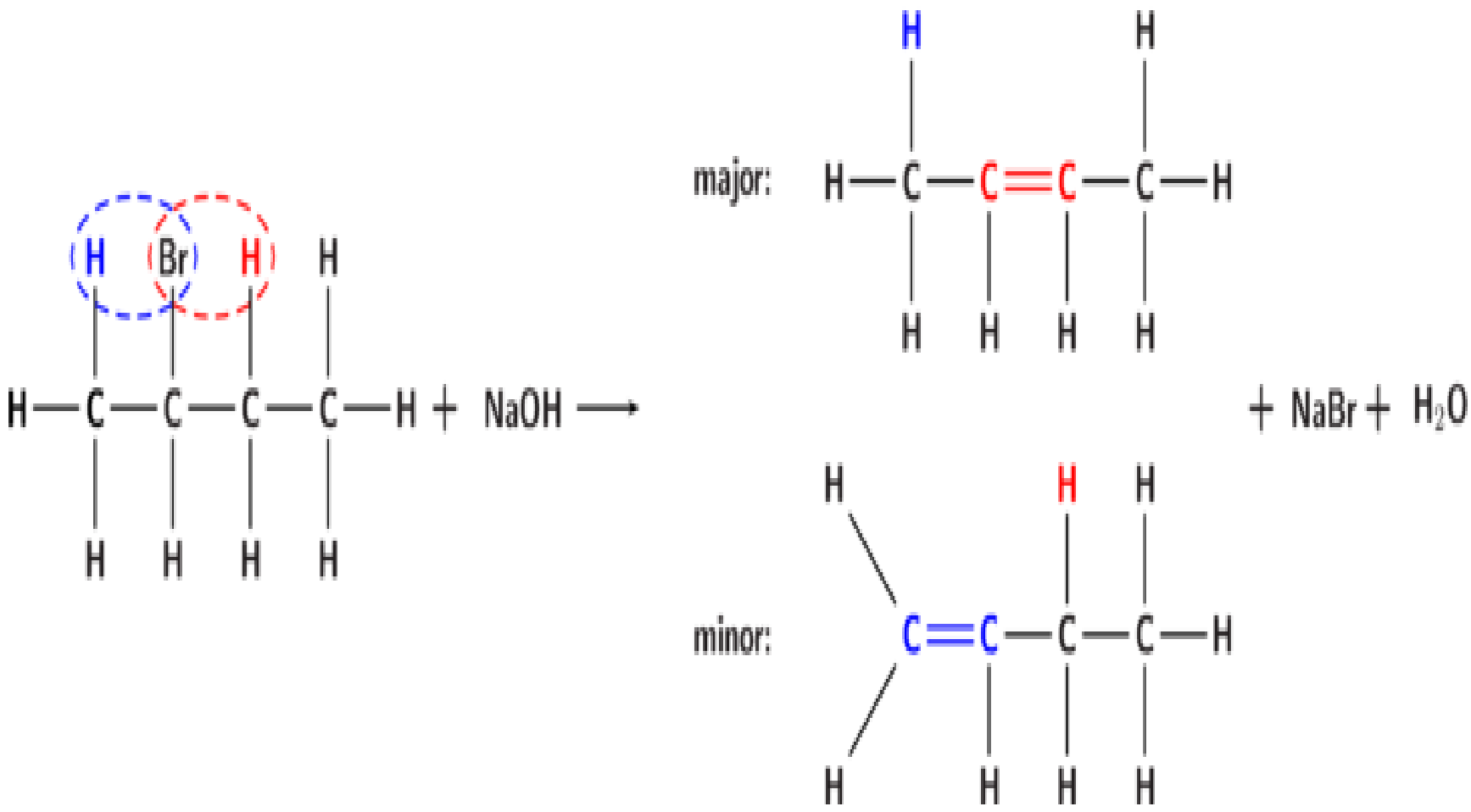


Hydrogenation continued,

- Reaction conditions: The alkene is dissolved in a non-polar solvent. Finely divided Ni, Pt or Pd is used as a catalyst in a hydrogen atmosphere. The H atoms attach to the carbon atoms that supported double bond.

Elimination Reactions

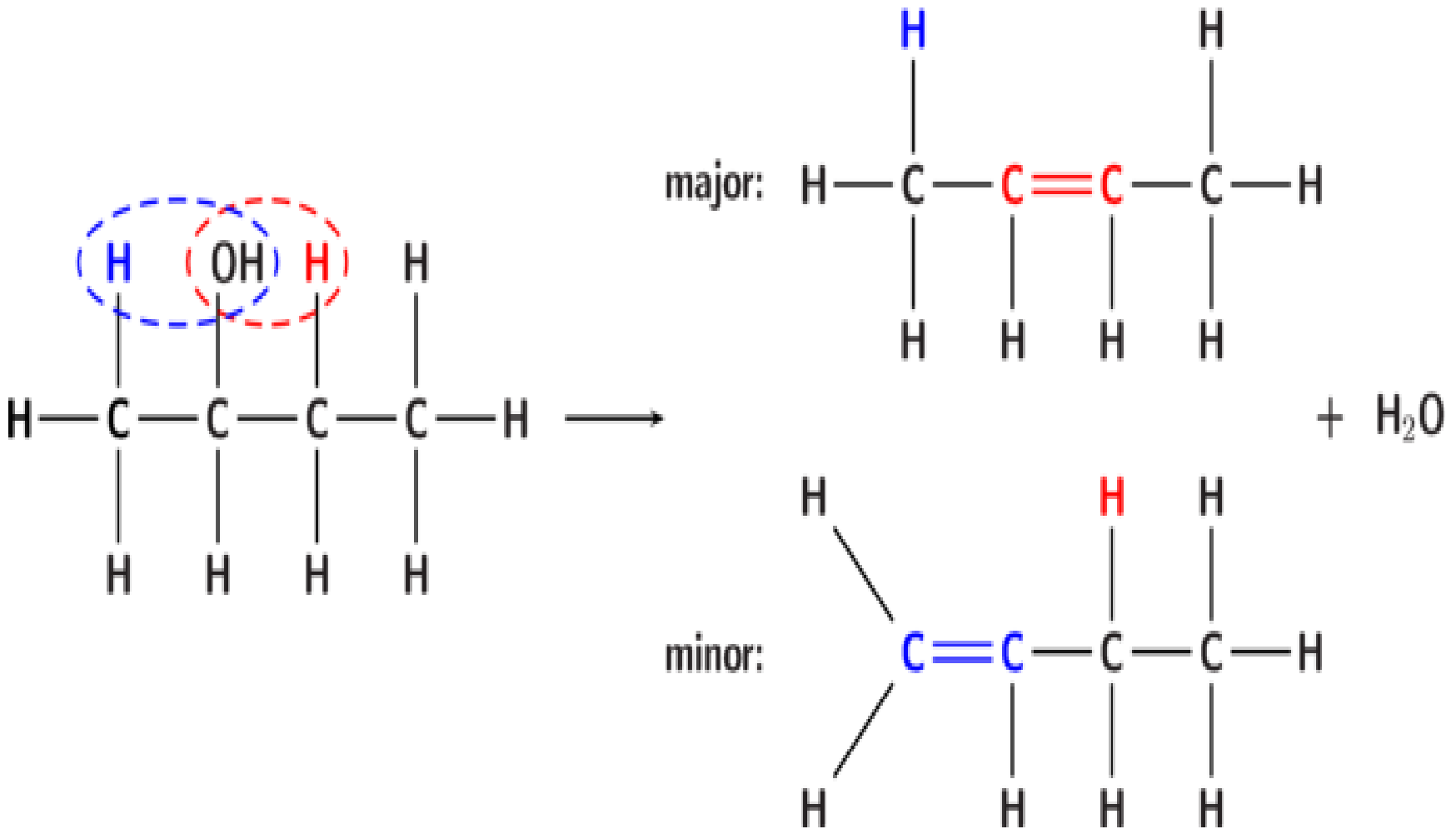
- **Dehydrohalogenation**
  - In dehydrohalogenation a **haloalkane** is exposed to a **base**, the base then helps the elimination of the halogen and a hydrogen atom. A double bond is formed (alkane → alkene). Dehydrohalogenation is considered the opposite of hydrohalogenation. An example of dehydrohalogenation


major:
minor:
NaOH
NaBr
H_2O

- Reaction conditions: Use concentrated NaOH or KOH in EtOH. Heat the mixture under reflux. The reaction favours the secondary or tertiary C atoms.

Dehydration of an alcohol

- During the dehydration of an alcohol the **hydroxyl** (−OH) group and a **hydrogen atom** are **eliminated** from the reactant. A molecule of water is formed as a product in the reaction, along with an alkene . This can be thought of as the reverse of a hydration (addition) reaction

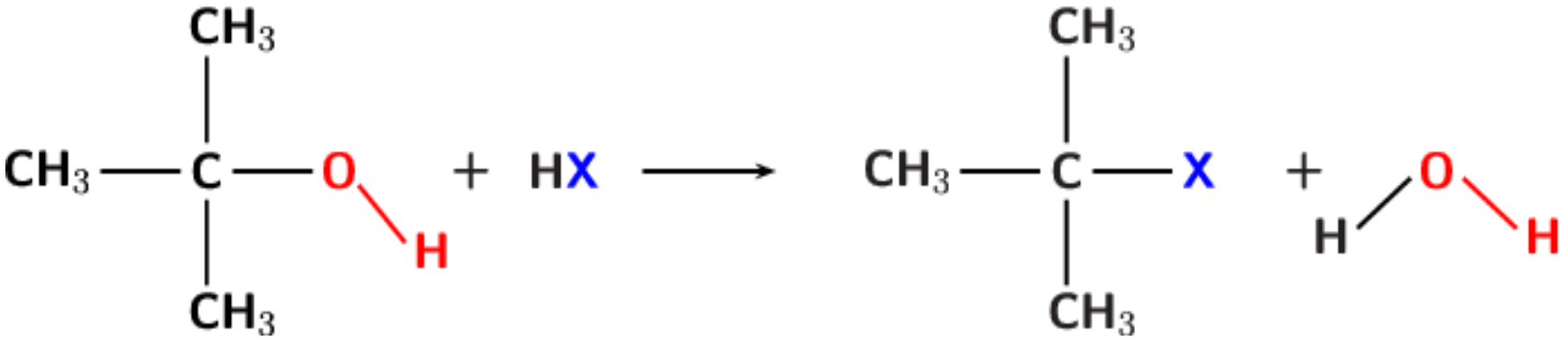

major:
minor:
+ H2O

- Reaction conditions: Alcohol is heated with concentrated H_2SO_4, or H_3PO_4 as a catalyst. The reaction favours the removal of H atoms from secondary or tertiary C atoms.

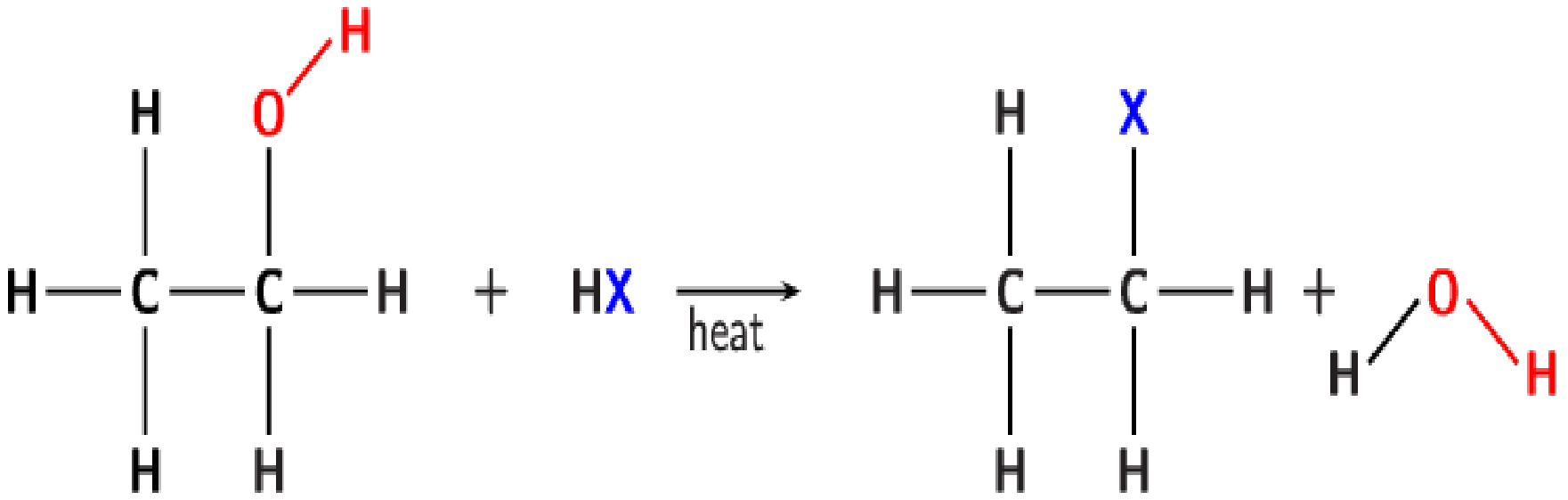
Substitution reactions

Formation of haloalkanes

– Haloalkanes can be formed when the hydroxyl (−OH) group of an alcohol is replaced by a halogen atom (X = Cl, Br). This reaction works best with tertiary alcohols where it can occur at room temperature.

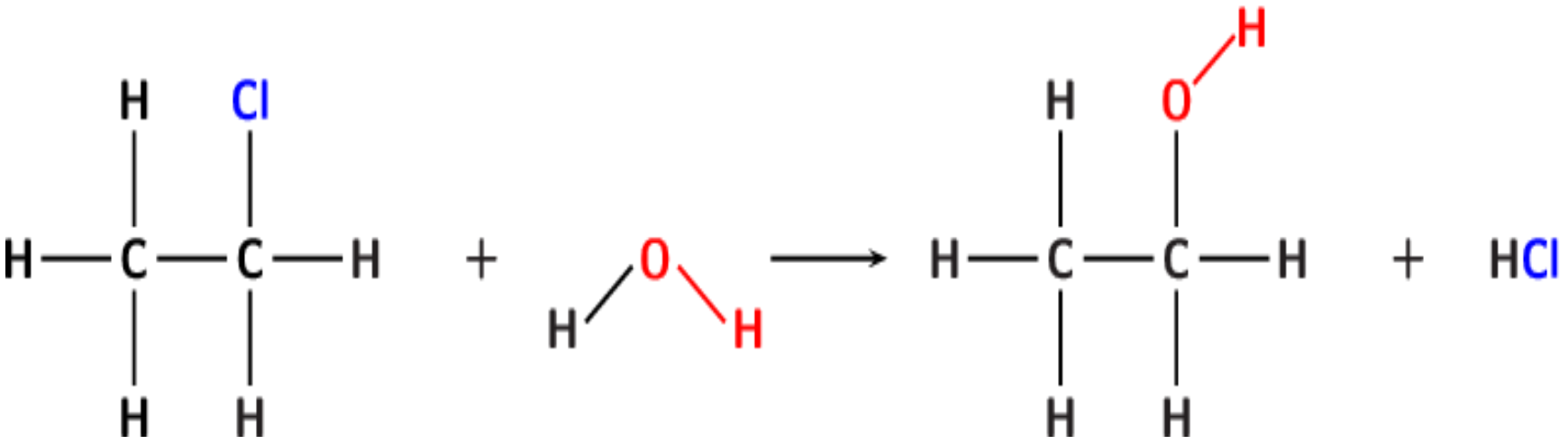


- Primary and secondary alcohols react slowly and with heating.

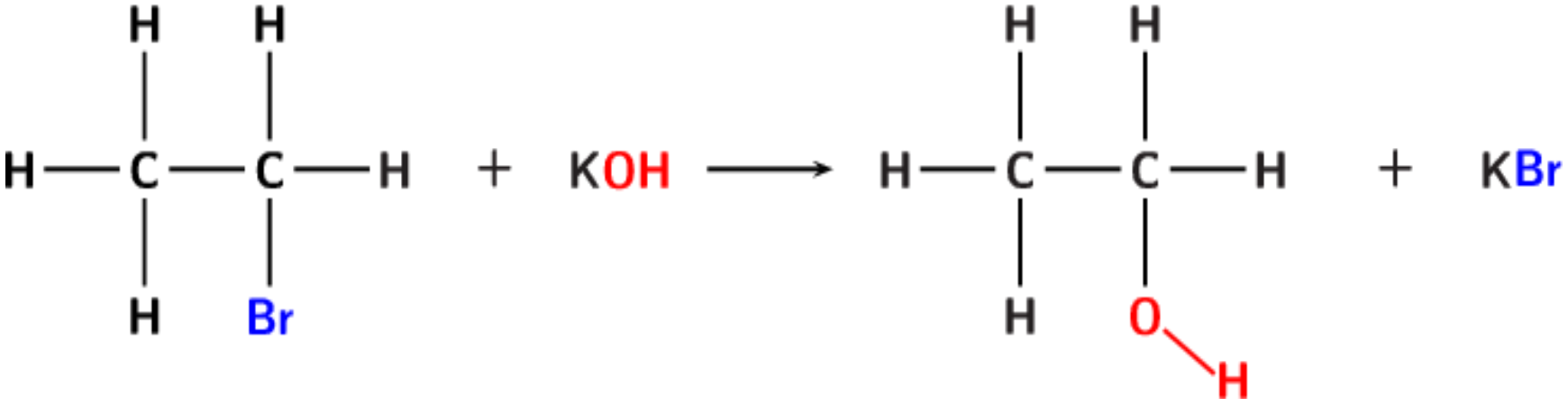


Hydrolysis

- Alcohols can also be formed through a substitution reaction with a haloalkane. In the example given below, the haloalkane would be dissolved in water.



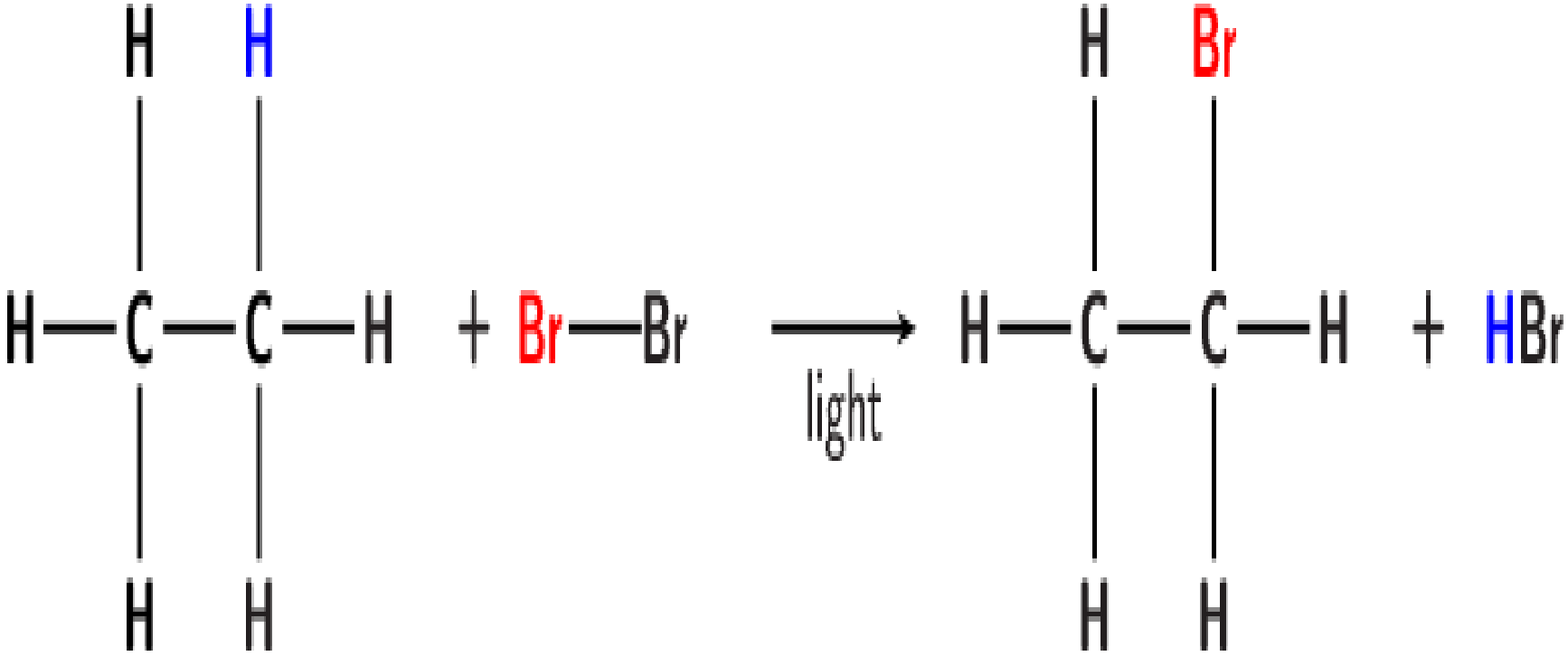
- Dissolve haloalkanes in EtOH, add dilute NaOH and warm the solution.
- The reaction also occurs without a base but at a slower rate.



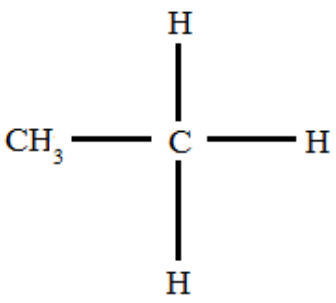
Formation of haloalkanes from alkanes

- Another way of forming a haloalkane involves the removal of a hydrogen atom from a saturated compound. The hydrogen atom is replaced by a halogen (F , Cl , Br or I) to form a haloalkane . As alkanes are not very reactive light is needed for this reaction to take place.

- UV light/Heat is need to catalyze this reaction.

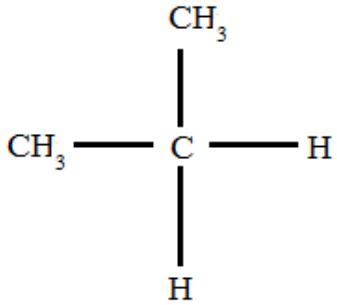


Primary, Secondary & Tertiary Carbons



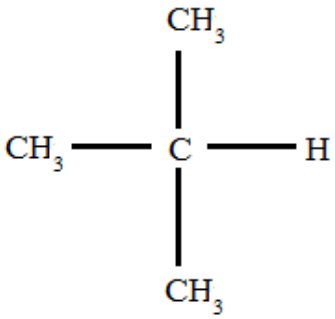
Alkanes: primary

1C, 3H



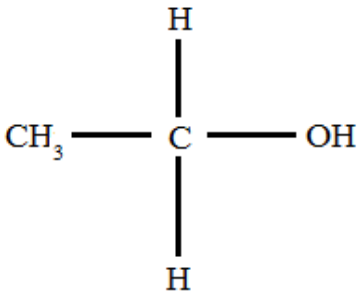
secondary

2C,2H



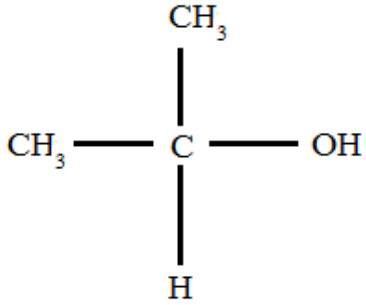
tertiary

3C,1H



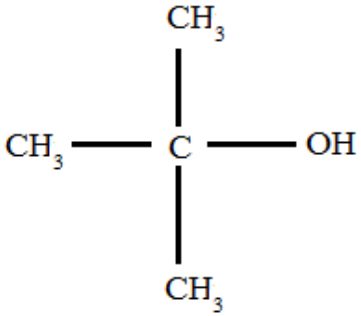
Alcohols: primary

1C, 2H



secondary

2C, 1H



tertiary

3C, 0H

Example 1

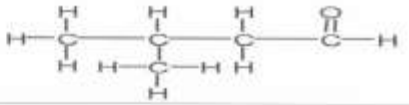
SECTION B

INSTRUCTIONS

1. Start EACH question on a NEW page.
2. Leave ONE line between two subquestions, for example between QUESTION 3.1 and QUESTION 3.2.
3. Show the formulae and substitutions in ALL calculations.
4. Round off your final numerical answers to a minimum of TWO decimal places.

QUESTION 3 (Start on a new page.)

The letters **A** to **F** in the table below represent six organic compounds.

A	$CH \equiv C-CH_2-CH_2-CH_3$	**B**	$CH_3CH_2CH_2CHCH_3$ (OH)
C	$CH_2=C(CH_3)-CH_2$ (CH_3)	**D**	Pentanoic acid
E		**F**	$CH_3-CH_2-O-C(=O)-CH_2-CH_3$

3.1 Write down the letter(s) that represent(s) each of the following:
(A compound may be used more than once.)

3.1.1 An alkyne (1)

3.1.2 Two compounds that are structural isomers (2)

3.1.3 A compound containing a carboxyl group (1)

3.1.4 An aldehyde (1)

3.1.5 An alcohol (1)

3.2 Write down the:

3.2.1 IUPAC name of compound **C** (2)

3.2.2 Structural formula of compound **D** (2)

Example 2

3.3 Compound **F** is prepared in the laboratory.

3.3.1 How can one quickly establish whether compound **F** is indeed being formed? (1)

3.3.2 Write down the IUPAC name of the alcohol needed to prepare compound **F**. (2)

3.3.3 Write down the IUPAC name of compound **F**. (2)
[15]

QUESTION 4 (Start on a new page.)

During a practical investigation the boiling points of the first six straight-chain ALKANES were determined and the results were recorded in the table below.

ALKANE	MOLECULAR FORMULA	BOILING POINT (°C)
Methane	CH_4	−164
Ethane	C_2H_6	−89
Propane	C_3H_8	−42
Butane	C_4H_{10}	−0,5
Pentane	C_5H_{12}	36
Hexane	C_6H_{14}	69

4.1 Write down the:

4.1.1 Most important use of the alkanes in the above table (1)

4.1.2 General formula of the alkanes (1)

Refer to the table to answer QUESTION 4.2 and QUESTION 4.3 below.

4.2 For this investigation, write down the following:

4.2.1 Dependent variable (1)

4.2.2 Independent variable (1)

4.2.3 Conclusion that can be drawn from the above results (2)

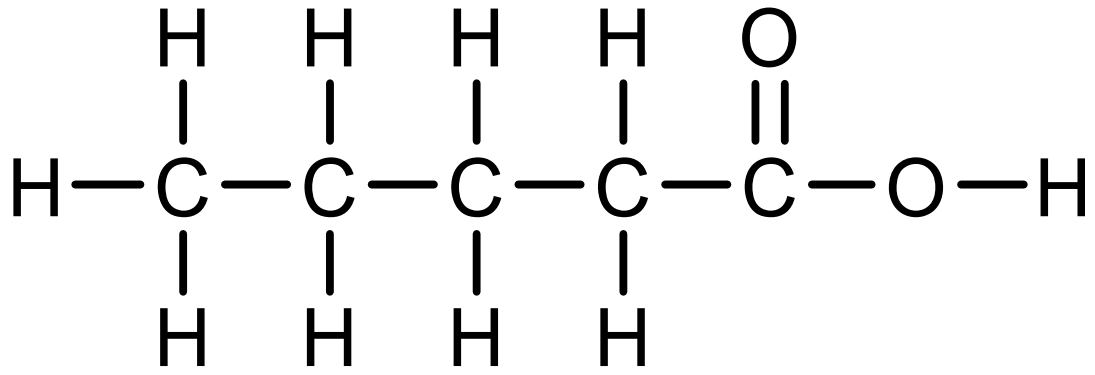
4.3 Write down the NAME of an alkane that is a liquid at 25 °C. (1)

4.4 Alkanes burn readily in oxygen. Write down a balanced equation, using molecular formulae, for the combustion of propane in excess oxygen. (3)

4.5 Will the boiling points of the structural isomers of hexane be HIGHER THAN, LOWER THAN or EQUAL TO that of hexane? Refer to MOLECULAR STRUCTURE, INTERMOLECULAR FORCES and ENERGY NEEDED to explain the answer. (4)
[14]

Answers

- 3.2.2



Answers

- 4.4

$$C_3H_8 + O_2 \longrightarrow CO_2 + H_2O$$

$$C_3H_8 + 5O_2 \longrightarrow 3CO_2 + 4H_2O$$

Example 3

QUESTION 5 (Start on a new page.)

The flow diagram below shows how three organic compounds can be prepared from 2-bromo-3-methylbutane.

5.1 Write down the:

5.1.1 Homologous series to which 2-bromo-3-methylbutane belongs (1)

5.1.2 Structural formula of 2-bromo-3-methylbutane (2)

5.2 **Reaction 2** takes place in the presence of a dilute sodium hydroxide solution.

Write down the:

5.2.1 Name of the type of reaction which takes place (1)

5.2.2 Structural formula of compound **B** (2)

5.3 **Reaction 1** takes place in the presence of concentrated sodium hydroxide.

Write down:

5.3.1 Another reaction condition needed for this reaction (1)

5.3.2 The name of the type of reaction which takes place (1)

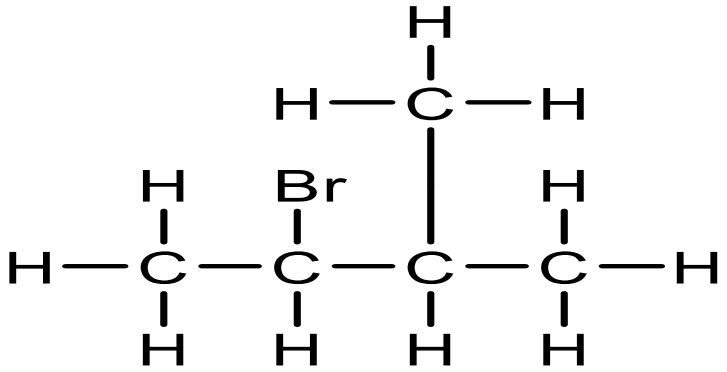
5.3.3 The structural formula of compound **A**, the major product formed (2)

5.4 **Reaction 3** takes place when compound **B** is heated in the presence of concentrated sulphuric acid. Write down the IUPAC name of the major product formed. (2)

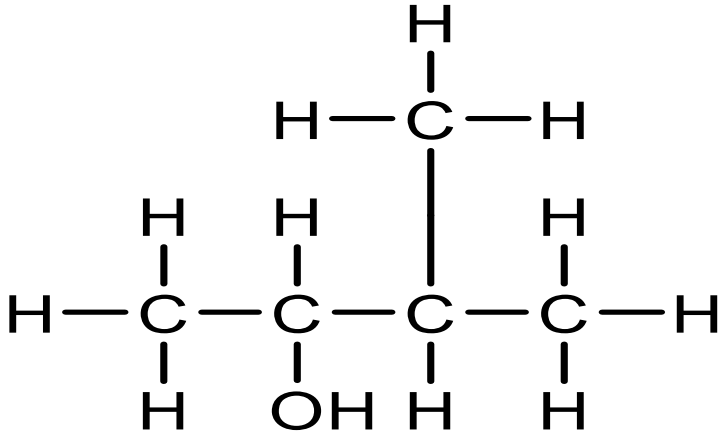
[12]

Answers

- 5.1.2

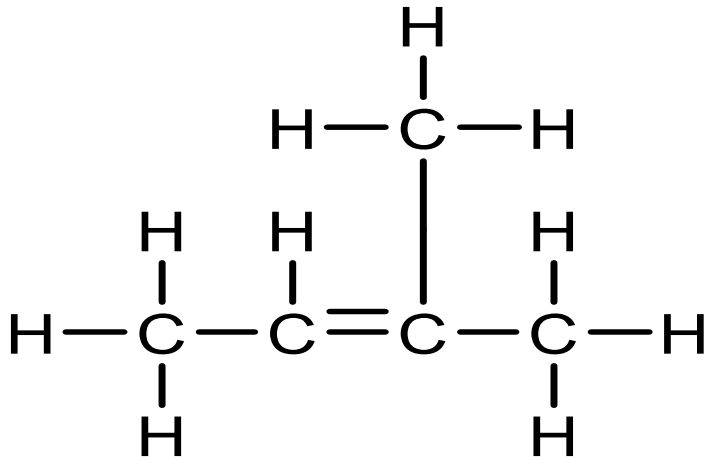


- 5.2.2



Answers

- 5.3.3



- 5.4 2-methylbut-2-ene

Example 4

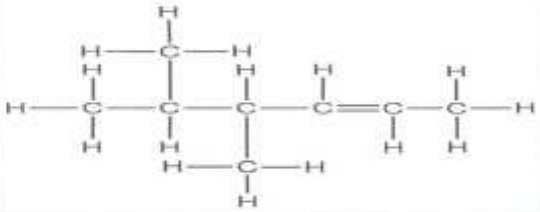
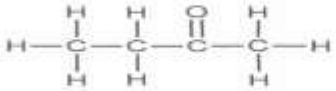
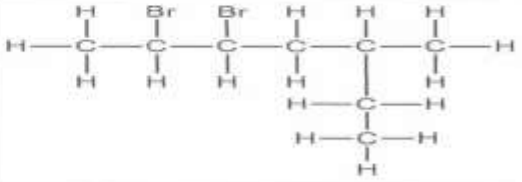
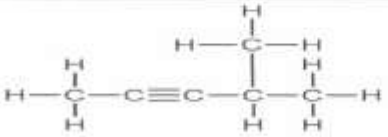
SECTION B

INSTRUCTIONS

1. Start EACH question on a NEW page.
2. Leave ONE line between two subquestions, for example between QUESTION 3.1 and QUESTION 3.2.
3. Show the formulae and substitutions in ALL calculations.
4. Round off your final numerical answers to a minimum of TWO decimal places.

QUESTION 3 (Start on a new page.)

The letters **A** to **F** in the table below represent six organic compounds.

A		**B**	
C	$CH_3CH=CHCH_2CH_2CH_3$	**D**	Pentyl propanoate
E		**F**	

3.1 Write down the letter(s) that represent(s) the following:

3.1.1 Alkenes (2)

3.1.2 A ketone (1)

3.1.3 A compound with the general formula C_nH_{2n-2} (1)

3.1.4 A structural isomer of cyclohexene (2)

Example 5

3.2 Write down the IUPAC name of compound:

3.2.1 **A** (2)

3.2.2 **E** (2)

3.2.3 **F** (2)

3.3 Compound **D** is prepared by reacting two organic compounds in the presence of an acid as catalyst.

Write down the:

3.3.1 Homologous series to which compound **D** belongs (1)

3.3.2 Structural formula of compound **D** (2)

3.3.3 IUPAC name of the organic acid used to prepare compound **D** (1)

3.3.4 NAME or FORMULA of the catalyst used (1)
[17]

QUESTION 4 (Start on a new page.)

A laboratory technician is supplied with three unlabelled bottles containing an alcohol, an aldehyde and an alkane respectively of comparable molecular mass. She takes a sample from each bottle and labels them **P**, **Q** and **R**.

In order to identify each sample, she determines the boiling point of each under the same conditions. The results are shown in the table below.

SAMPLE	BOILING POINT (°C)
P	76
Q	36
R	118

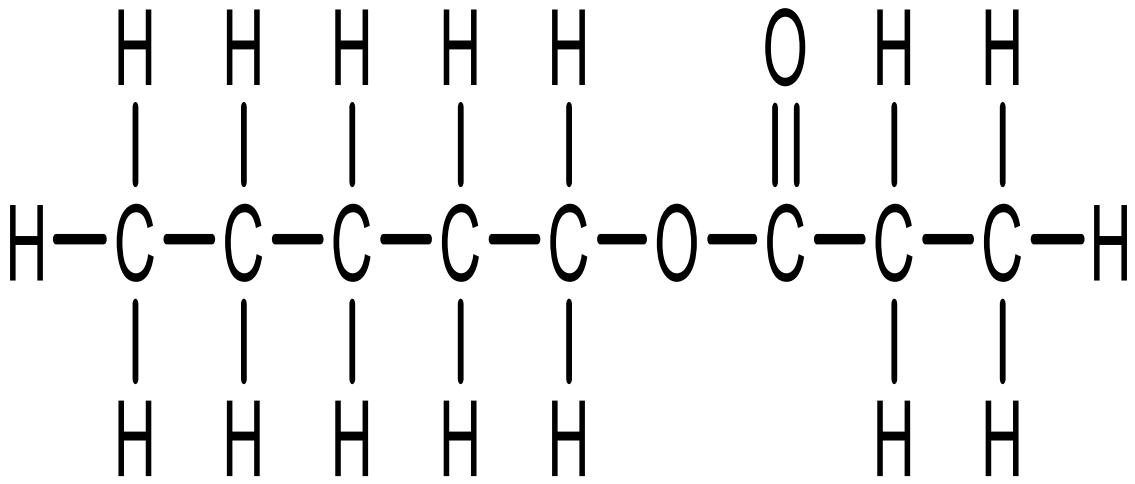
4.1 For this investigation, write down the:

4.1.1 Independent variable (1)

4.1.2 Dependent variable (1)

4.2 From the passage above, write down a phrase that shows that this investigation is a fair test. (1)

- 3.3.2



Example 6

4.3 Which sample (**P**, **Q** or **R**) is the:

4.3.1 Alkane (1)

4.3.2 Alcohol (1)

4.3.3 Refer to boiling point and the type of intermolecular forces present between alcohol molecules to give a reason for the answer in QUESTION 4.3.2. (2)

4.4 The alkane is identified as pentane. Will the boiling point of hexane be HIGHER THAN or LOWER THAN that of pentane? Refer to MOLECULAR STRUCTURE, INTERMOLECULAR FORCES and ENERGY needed to explain the answer. (4)
[11]

QUESTION 5 (Start on a new page.)

Two straight chain compounds, **P** and **Q**, each have the following molecular formula:

P: C_4H_{10}

Q: C_4H_8

5.1 Write down the name of the homologous series to which **Q** belongs. (1)

5.2 Compound **P** reacts with chlorine to form 2-chlorobutane.

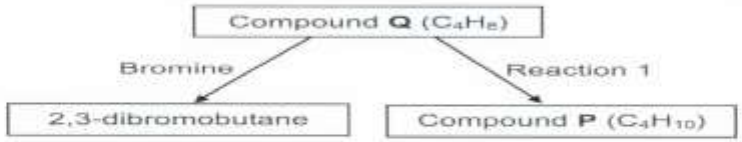
Write down:

5.2.1 A balanced chemical equation, using MOLECULAR FORMULAE, for the reaction that takes place (3)

5.2.2 The type of reaction that takes place (1)

5.2.3 One reaction condition (other than the solvent needed) (1)

5.3 Compound **Q** takes part in reactions as shown in the flow diagram below.



Write down the:

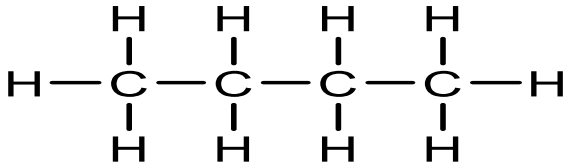
5.3.1 Structural formula for 2,3-dibromobutane (2)

5.3.2 IUPAC name of compound **Q** (2)

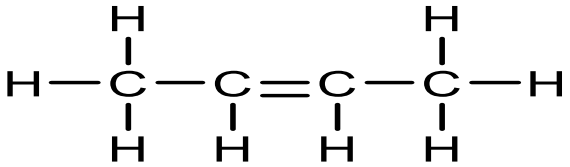
5.3.3 Balanced equation, using structural formulae, for **reaction 1** (4)

5.3.4 Type of reaction that occurs in **reaction 1** (1)
[15]

Answers

- 5.1 

P



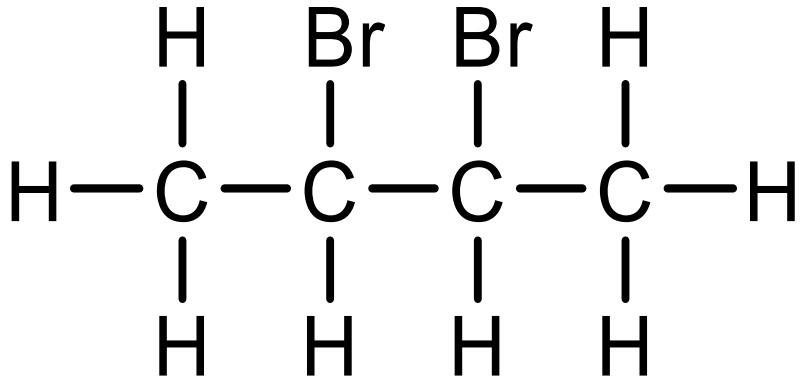
Q

- 5.2.1

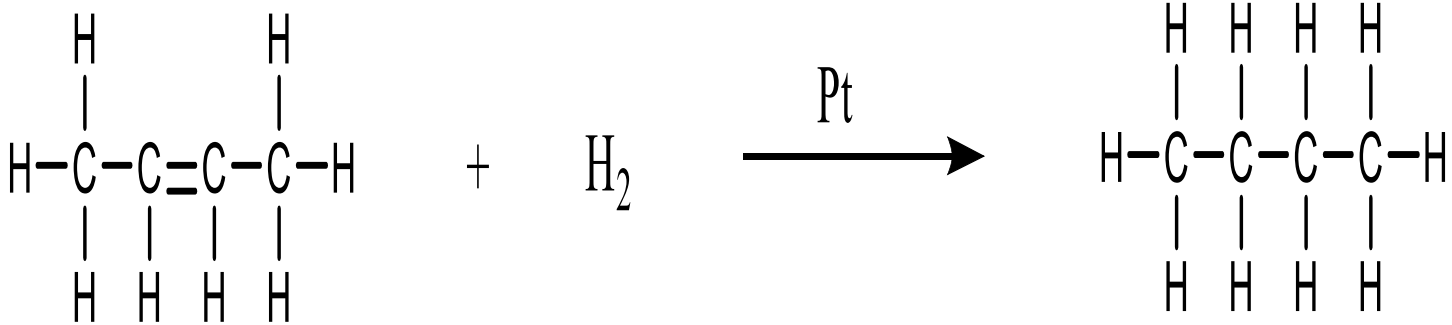
$$C_4H_{10} + Cl_2 \xrightarrow{UV} C_4H_9Cl + HCl$$

Answers

- 5.3.1



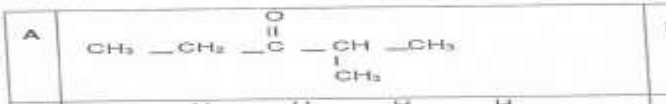
- 5.3.3



Example 7

QUESTION 2

Consider the following representation of organic molecules **A** to **F** listed in the table below:

A		**B**	
C		**D**	Methanal
E	2-methylhex-3-yne	**F**	

2.1 Write down the letter that represents a compound that:

2.1.1 Is an aldehyde (1)
2.1.2 Is a saturated hydrocarbon (1)
2.1.3 Has a general formula C_nH_{2n-2} (1)

2.2 Write down the homologous series to which each of the following compounds belongs:

2.2.1 **A** (1)
2.2.2 **B** (1)
2.2.3 **F** (1)

2.3 Write down the:

2.3.1 Molecular formula of the next compound in the same homologous series as compound **C**. (1)
2.3.2 Structural formula of compound **E** (2)
2.3.3 IUPAC name of compound **B** (2)
2.3.4 Functional group of compound **D** (1)

[12]

QUESTION 3

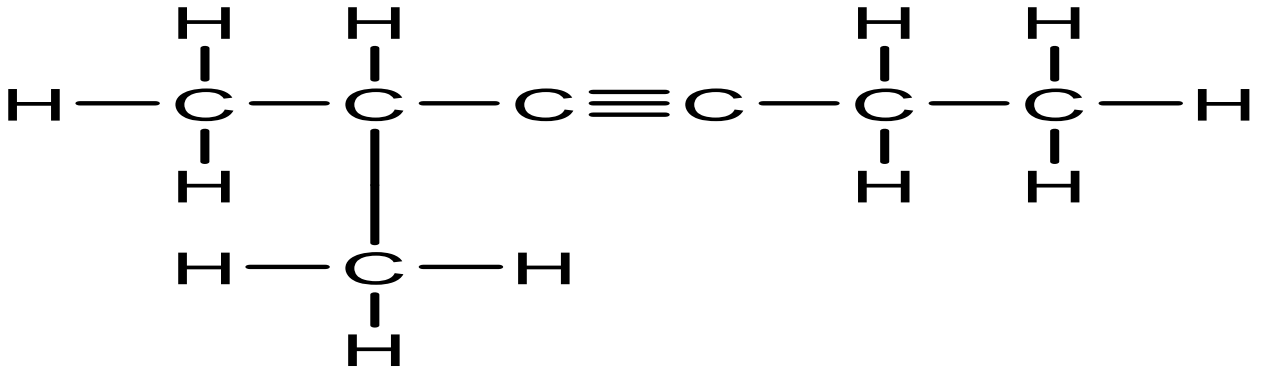
Two compounds **A** and **B**, have the molecular formula $C_2H_4O_2$.

3.1 What is meant by the term **structural isomers**? (2)
3.2 Compound A has a lower vapour pressure than compound B.
3.2.1 How will the boiling point of compound A compare to that of compound B. Only write HIGHER THAN, LOWER THAN, or EQUAL TO. (1)
3.2.2 Write down the name of compound A. (1)
3.2.3 To which class of organic compound does compound B belong? (1)
3.2.4 Write down the structural formula for compound B and give its IUPAC name. (3)
3.2.5 Explain in terms of intermolecular forces and energy why compound A has a lower vapour pressure than compound B. (3)

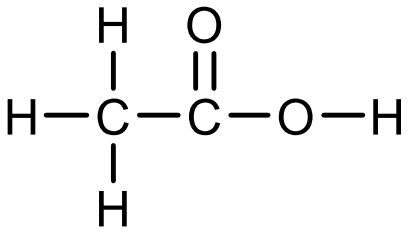
[11]

Answers

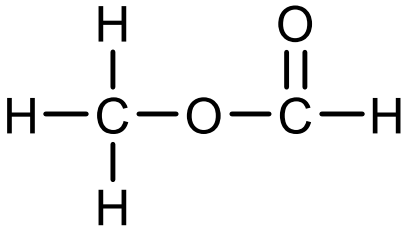
- 2.3.2



- 3



A

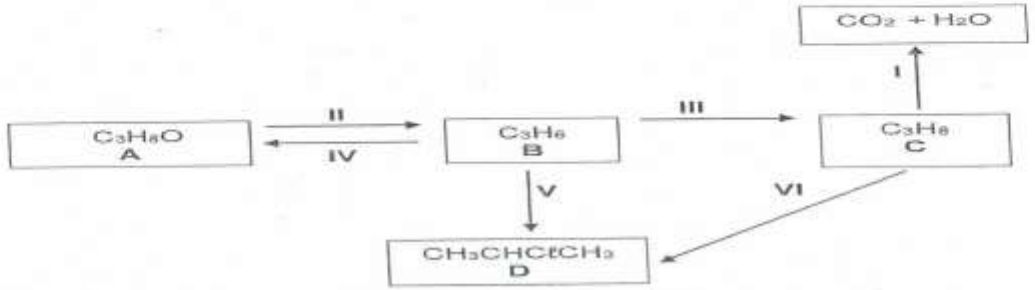


B

Example 8

QUESTION 4

Consider the following sequence of organic reactions and then answer the questions that follow. Reactions are labeled from **I** to **VI** while organic compounds are labeled from **A** to **D**.



4.1 Give the reagent needed for each of the following reactions:
- 4.1.1 Reaction **III** (1)
- 4.1.2 Reaction **V** (1)

4.2 Compound **A** is a major product of reaction IV.
- 4.2.1 Name the type of reaction that takes place. (1)
- 4.2.2 Write down the structural formula of compound **A**. (2)

4.3 Reaction **II** converts compound **A** to compound **B** in the presence of concentrated sulphuric acid.
- 4.3.1 Is compound **A** a PRIMARY, SECONDARY or TERTIARY alcohol? (1)
- 4.3.2 Name the type of reaction that takes place. (1)

4.4 Reaction **I** is a combustion reaction.
- 4.4.1 Write down the balanced chemical equation for this reaction. (2)
- 4.4.2 Eleven grams (11g) of C_3H_8 undergoes complete combustion. Determine the mass of CO_2 gas produced at STP. (4)

[13]

QUESTION 5

A manufacturer makes a polymer, polyethene from the monomer, ethene by means of addition polymerisation. The polymer produced has an average relative molecular mass of $1,0 \times 10^4$.

5.1 What is meant by the following terms?
- 5.1.1 monomer (2)
- 5.1.2 polymerisation (2)

5.2 Write down an equation for the polymerisation of ethene to produce polyethene. (3)

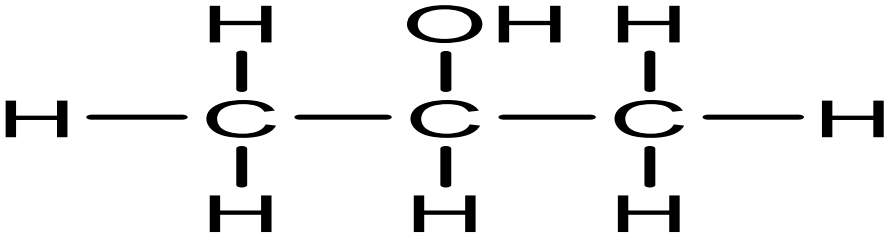
5.3 How many monomer units are joined together to give polyethene with a relative molecular mass of 1.0×10^4? (2)

5.4 Most plastic bags are made from polyethene. Give one negative impact of the use of plastics on the environment. (1)

[10]

Answers

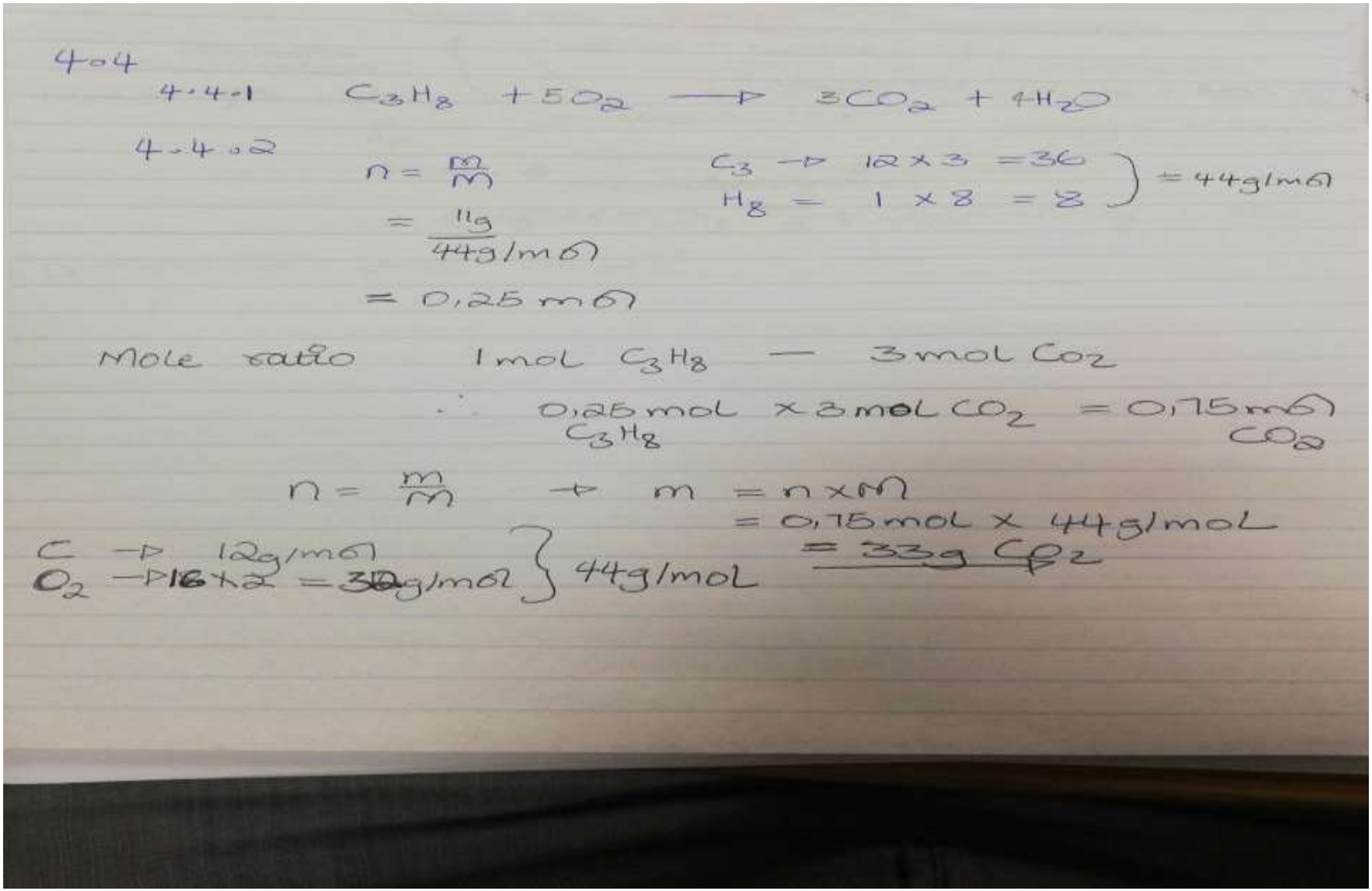
- 4.2.2



- 4.4.1 $C_3H_8 + O_2 \longrightarrow CO_2 + H_2O$

$C_3H_8 + 5O_2 \longrightarrow 3CO_2 + 4H_2O$

Answers


4.4
4.4.1 $C_3H_8 + 5O_2 \longrightarrow 3CO_2 + 4H_2O$
4.4.2
$n = \frac{m}{M}$
$= \frac{11g}{44g/mol}$
$= 0,25 mol$
$C_3 \rightarrow 12 \times 3 = 36$
$H_8 = 1 \times 8 = 8$
$= 44g/mol$
Mole ratio 1 mol C_3H_8 — 3 mol CO_2
$0,25 mol\ C_3H_8 \times 3 mol\ CO_2 = 0,75 mol\ CO_2$
$n = \frac{m}{M} \rightarrow m = n \times M$
$= 0,75 mol \times 44g/mol$
$= 33g\ CO_2$
$C \rightarrow 12g/mol$
$O_2 \rightarrow 16 \times 2 = 32g/mol$
$44g/mol$