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Learner Revision Guide
Grade 12

PHYSICAL SCIENCES: Organic Molecules



education

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FREE STATE PROVINCE

UNIVERSITY OF THE
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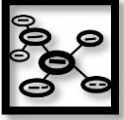
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1. Outcomes

You should be able to answer questions on the concepts outlined below.

- Define *organic molecules* as molecules containing carbon atoms.

Organic molecular structures – functional groups, saturated and unsaturated structures, isomers

- Write down condensed structural formulae, structural formulae and molecular formulae (up to 8 carbon atoms, one functional group per molecule) for:
 - Alkanes (no ring structures)
 - Alkenes (no ring structures)
 - Alkynes
 - Halo-alkanes (primary, secondary and tertiary haloalkanes; no ring structures)
 - Alcohols (primary, secondary and tertiary alcohols)
 - Carboxylic acids
 - Esters
 - Aldehydes
 - Ketones
- Know the following definitions/terms: molecular formula, structural formula; hydrocarbon; homologous series; saturated compounds; unsaturated compounds; functional group; structural isomer
- Identify compounds (up to 8 carbon atoms) that are saturated, unsaturated and are structural isomers.
- Restrict structural isomers to chain isomers, positional isomers and functional isomers.

IUPAC naming and formulae

- Write down the IUPAC name when given the structural formula or condensed structural formula for compounds from the homologous series above, restricted to one functional group per compound, except for haloalkanes. For haloalkanes, maximum two functional groups per molecule.
- Write down the structural formula when given the IUPAC name for the above homologous series.
- Identify alkyl substituents (methyl- and ethyl-) in a chain to a maximum of THREE alkyl substituents on the parent chain.
- When naming haloalkanes, the halogen atoms do not get preference over alkyl groups – numbering should start from the end nearest to the first substituent, either the alkyl group or the halogen. In haloalkanes, where e.g. a Br and a Cl have the same number when numbered from different ends of chain, Br gets alphabetical preference.
- When writing IUPAC names, substituents appear as prefixes written alphabetically (bromo, chloro, ethyl, methyl), ignoring the prefixes di- and tri.

Physical properties

- For a given example (from the above functional groups), explain the relationship between physical properties and:
 - Strength of intermolecular forces (Van der Waal's forces), i.e. hydrogen bonds, dipole-dipole forces, induced dipole forces
 - Type of functional groups
 - Chain length
 - Branched chains

Oxidation of alkanes

- State the use of alkanes as fuels.
- Write down an equation for the combustion of an alkane in excess oxygen.

Esterification

- Write down an equation, using structural formulae, for the formation of an ester.
- Name the alcohol and carboxylic acid used and the ester formed.
- Write down reaction conditions for esterification.

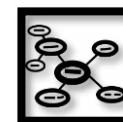
Substitution, addition and elimination reactions

- Identify reactions as elimination, substitution or addition.
- Write down, using structural formulae, equations and reaction conditions for the following addition reactions of alkenes:
 - Hydrohalogenation
 - Halogenation
 - Hydration
 - Hydrogenation
- Write down, using structural formulae, equations and reaction conditions for the following elimination reactions:
 - Dehydrohalogenation of haloalkanes
 - Dehydration of alcohols
 - Cracking of alkanes
- Write down, using structural formulae, equations and reaction conditions for the following substitution reactions:
 - Hydrolysis of haloalkanes
 - Reactions of HX (X = Cl, Br) with alcohols to produce haloalkanes
 - Halogenation of alkanes
- Distinguish between *saturated* and *unsaturated hydrocarbons* using bromine water.

Plastics and polymers (only basic polymerisation as application of organic chemistry)

- Describe the following terms: macromolecule; polymer; monomer; polymerization
- Distinguish between *addition polymerisation* and *condensation polymerization*.
- Identify monomers from given addition polymers.
- Write down an equation for the polymerisation of ethene to produce polythene.
- State the industrial uses of polythene.

2. Topic mind map



ORGANIC MOLECULES									
Homologous series	Hydrocarbons			Haloalkanes	Alcohols	Aldehydes	Ketones	Carboxylic acids	Esters
	Alkanes	Alkenes	Alkynes						
General formula	C_nH_{2n+2}	C_nH_{2n}	C_nH_{2n-2}	$C_nH_{2n+1}X$	$C_nH_{2n+1}OH$	$C_nH_{2n}O$	$C_nH_{2n}O$	$C_nH_{2n}O_2$	$C_nH_{2n}O_2$
Functional group	$\begin{array}{c} & \\ -C- & -C- \\ & \end{array}$	$\begin{array}{c} \diagup & \diagdown \\ C & = & C \\ \diagdown & \diagup \end{array}$	$-C \equiv C-$	$\begin{array}{c} \\ -C-X \\ \end{array}$	$\begin{array}{c} \\ -C-OH \\ \end{array}$	$\begin{array}{c} O \\ \\ -C-H \end{array}$	$\begin{array}{c} O \\ \\ -C-C(=O)- \\ & \end{array}$	$\begin{array}{c} O \\ \\ -C-O-H \end{array}$	$\begin{array}{c} O \\ \\ -C-O-C- \\ & \end{array}$
Example structural formula	$\begin{array}{c} H & H \\ & \\ H-C & -C-H \\ & \\ H & H \end{array}$	$\begin{array}{c} H & & H \\ & \diagdown & / \\ & C = C \\ & / & \diagdown \\ H & & H \end{array}$	$H-C \equiv C-H$	$\begin{array}{c} H & H \\ & \\ H-C & -C-H \\ & \\ H & Br \end{array}$	$\begin{array}{c} H & H \\ & \\ H-C & -C-H \\ & \\ H & OH \end{array}$	$\begin{array}{c} H & O \\ & \\ H-C & -C-H \\ & \\ H & \end{array}$	$\begin{array}{c} H & O & H \\ & & \\ H-C & -C & -C-H \\ & & \\ H & & H \end{array}$	$\begin{array}{c} H & O \\ & \\ H-C & -C-O-H \\ & \\ H & \end{array}$	$\begin{array}{c} H & O & H \\ & & \\ H-C & -C & -O-C-H \\ & & \\ H & & H \end{array}$
Example IUPAC name	Ethane	Ethene	Ethyne	Bromoethane	Ethanol	Ethanal	Propanone	Ethanoic acid	Methyl ethanoate
Intermolecular forces	London forces								
					Dipole-dipole forces				
								Hydrogen Bonding	
Chemical reactions	Oxidation Cracking Substitution	Addition		Substitution Elimination	Elimination Substitution Esterification			Esterification	

3. UNIT 1: Structure of organic molecules



Organic Chemistry is the **chemistry of carbon compounds**.

1.1 Homologous series

A family of organic compounds is referred to as a homologous series. Per definition a **homologous series** is a group of organic compounds that can be described by the same general formula and have the same functional group OR in which one member differs from the next with a $-\text{CH}_2$ group.

1.2 General formulae

A **general formula** can be used to determine the molecular formula of any member in a homologous series.

Table 1: General formulae of organic compound

Homologous series	General formula
Alkanes	$\text{C}_n\text{H}_{2n+2}$
Alkenes	C_nH_{2n}
Alkynes	$\text{C}_n\text{H}_{2n-2}$
Haloalkanes	$\text{C}_n\text{H}_{2n+1}\text{X}$
Alcohols	$\text{C}_n\text{H}_{2n+1}\text{OH}$
Aldehydes	$\text{C}_n\text{H}_{2n}\text{O}$
Ketones	$\text{C}_n\text{H}_{2n}\text{O}$
Carboxylic acids	$\text{C}_n\text{H}_{2n}\text{O}_2$
Esters	$\text{C}_n\text{H}_{2n}\text{O}_2$

1.3 Functional groups

A functional group is a bond, an atom or a group of atoms that determine(s) the physical and chemical properties of a group of organic compounds.

The functional groups of the nine homologous series' that you must learn are listed in table 2 below.



Remember to show ALL bonds around C atoms when drawing the structural formula of a functional group.

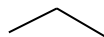
Table 2: Functional groups of organic compounds

Homologous series	Structure of functional group	
	Structure	Name/Description
Alkanes	$\begin{array}{c} \quad \\ -C-C- \\ \quad \end{array}$	Only C-H and C-C single bonds
Alkenes	$\begin{array}{c} \diagup \quad \diagdown \\ C=C \\ \diagdown \quad \diagup \end{array}$	Carbon-carbon double bond
Alkynes	$-C \equiv C-$	Carbon-carbon triple bond
Haloalkanes	$\begin{array}{c} \\ -C-X \\ \end{array}$ (X = F, Cl, Br, I)	Halogen atom bonded to a saturated C atom
Alcohols	$\begin{array}{c} \\ -C-O-H \\ \end{array}$	Hydroxyl group bonded to a saturated C atom
Aldehydes	$\begin{array}{c} O \\ \\ -C-H \end{array}$	Formyl group
Ketones	$\begin{array}{c} O \\ \\ -C-C-C- \\ \quad \quad \end{array}$	Carbonyl group bonded to two C atoms
Carboxylic acids	$\begin{array}{c} O \\ \\ -C-O-H \end{array}$	Carboxyl group
Esters	$\begin{array}{c} O \\ \\ -C-O-C- \\ \end{array}$	-

1.4 Representing organic molecules

When representing organic molecules, different types of formulae and structures may be used. Table 3 below summarises the different types of formulae and structures that can be used.

Table 3: Representation of organic molecules

Type of formula	Definition	Example
Molecular formula	A chemical formula that indicates the type of atoms and the correct number of each in a molecule.	C_3H_8
Condensed structural formula	This notation shows the way in which atoms are bonded together in the molecule, but DOES NOT SHOW ALL bond lines.	$\text{CH}_3\text{CH}_2\text{CH}_3$
Structural formula	A structural formula of a compound shows which atoms are attached to which within the molecule. Atoms are represented by their chemical symbols and lines are used to represent ALL the bonds that hold the atoms together.	<pre> H H H H—C—C—C—H H H H</pre>
Skeletal formula or line structure	Lines represent bonds, and intersections represent C atoms. H atoms are not indicated. Other atoms shown as in structural formula.	

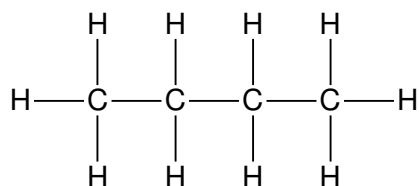
1.5 Isomerism

Isomers are compounds with the same molecular formula, but different structures.

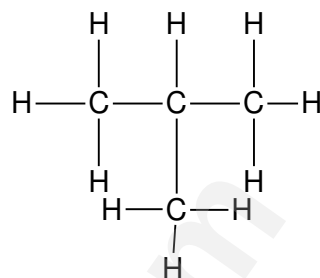
Structural isomers are compounds with the same molecular formula, but different structural formulae.



Ask your teacher for molecular models e.g. a ball and stick model may be used to show how the same atoms can be arranged in different ways to form different molecules. This is also one of the reasons for the millions of organic compounds known.



Butane



2-methylpropane

These two compounds have the same number and type of atoms, but are different compounds due to the different arrangement of the atoms.

Structural isomers can be further divided into chain isomers, positional isomers and functional isomers.

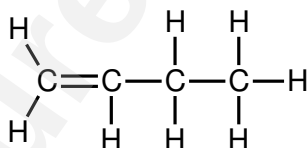
- Chain isomers**

Chain isomers have the same molecular formula, but different types of chains. Butane and 2-methylpropane are chain isomers.

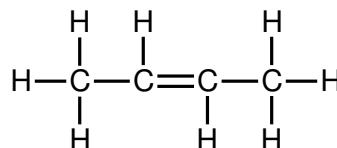
- Positional isomers**

Positional isomers have the same molecular formula, but different positions of the side chain, substituents or functional groups on the parent chain. Examples of positional isomers are shown below.

Different positions of the functional group

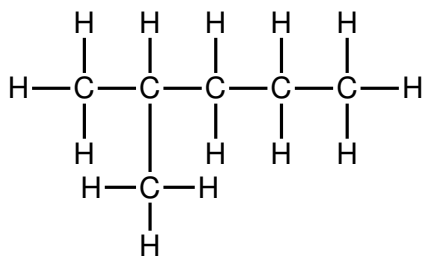


But-1-ene

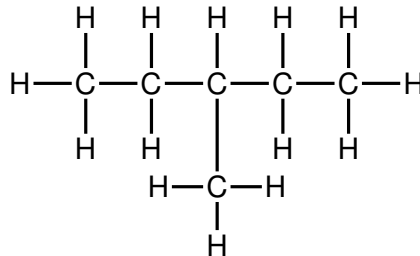


But-2-ene

Different positions of the side chain or substituent



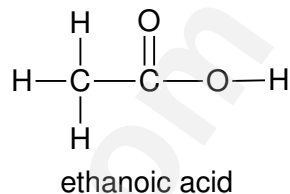
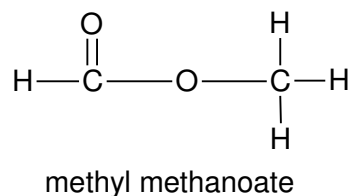
2-methylpentane



3-methylpentane

- **Functional isomers**

Functional isomers have the same molecular formula, but different functional groups, e.g. methyl methanoate and ethanoic acid.



1.6 Nomenclature of organic compounds

The IUPAC name of every organic molecule has three parts:

- The **parent name** indicates the number of C atoms in the longest continuous carbon chain in the molecule.
- The **suffix** indicates what functional group is present.
- The **prefix** reveals the identity, location and number of substituents attached to the carbon chain.

prefix

What and where are the substituents?

parent

How many carbons?

suffix

What is the functional group/homologous series?

Functional groups are indicated in Table 1. Table 4 shows the parent names used for compounds containing one to eight carbon atoms in the parent chain.

Table 4: Parent name for one to eight carbon atoms

Number of carbon atoms	Parent name	Number of carbon atoms	Parent name
1	meth	5	pent
2	eth	6	hex
3	prop	7	hept
4	but	8	oct

1.6.1 IUPAC names of hydrocarbons

Hydrocarbons are compounds consisting of carbon and hydrogen only. These compounds include alkanes, alkenes and alkynes.

(a) Alkanes

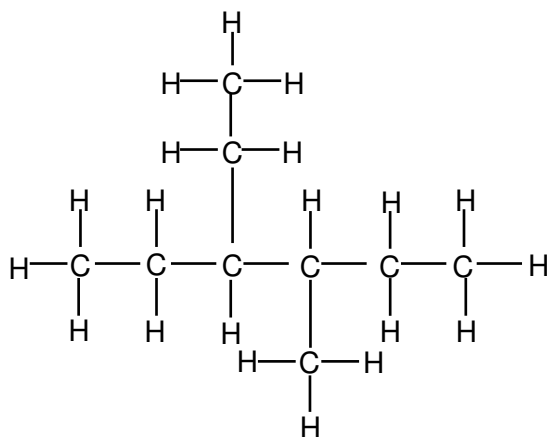
Fast facts

- Alkanes are organic compounds containing only C-H and C-C single bonds.
- General formula: C_nH_{2n+2}
- Functional group: Only C-H and C-C single bonds
- Alkanes are saturated hydrocarbons
Why hydrocarbons? They consist of hydrogen and carbon atoms only.
Why saturated? They have only C-C single bonds or each C atom is bonded to the maximum number of atoms i.e. four.
- Many alkanes occur in nature, mainly as natural gas and petroleum, which are both non-renewable sources of energy. Natural gas is mainly methane, the first alkane in the series. Petrol consists mainly of the alkanes containing from six to twelve carbon atoms.

Example 1

The IUPAC name of the accompanying compound can be determined as follows:

- The compound is a hydrocarbon with only C-C single bonds – an alkane. The name ends on –*ane*.
 - The longest chain contains 6 C atoms - the parent name is *hex-*.
 - One substituent has 1 C atom - *methyl* group. Another substituent contains 2 C atoms - an *ethyl* group.
 - Numbered from the left, the *methyl* group is on C4 and the *ethyl* group on C3. Numbered from the right, the *methyl* group is on C3 and the *ethyl* group on C4. Numbering from either side gives the same result, but alphabetically *ethyl* comes before *methyl*. Commas separate numbers, while hyphens separate numbers and prefixes.
- The compound is **3-ethyl-4-methylhexane**.



(b) Alkenes

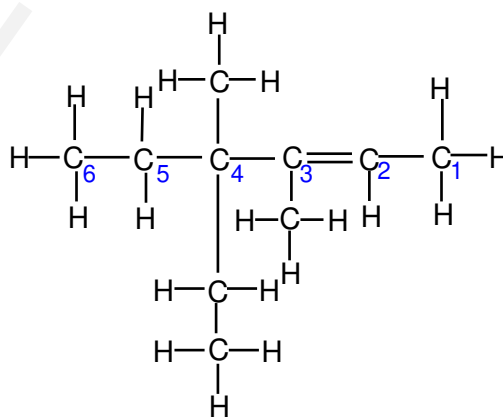
Fast facts

- An alkene is a compound of carbon and hydrogen that contains a **carbon-carbon double bond**.
- General formula: C_nH_{2n}
- Functional group: carbon-carbon double bond
- Alkenes are **unsaturated hydrocarbons**.
Why hydrocarbons? They consist of hydrogen and carbon atoms only.
Why unsaturated? They have carbon-carbon double bonds.

Example 2

The IUPAC name of the accompanying compound can be determined as follows:

- The compound is a hydrocarbon with a carbon-carbon double bond – an alkene. The name ends on *-ene*.
- The longest chain containing the double bond has 6 C atoms - the parent name is *hex-*.
- If numbered from the right, the double bond is after C2. If numbered from the left, the double bond is after C4. The former gives the double bond the lower number.
- Place the number -2- of the double bond between the parent name and the suffix. Use a hyphen between the number and the suffix and between the number and the parent name.
- The substituents are on C3 and C4. *Ethyl* before *methyl* and *two methyl* groups become *dimethyl*. The compound is **4-ethyl-3,4-dimethylhex-2-ene**.



(c) Alkynes

Fast facts

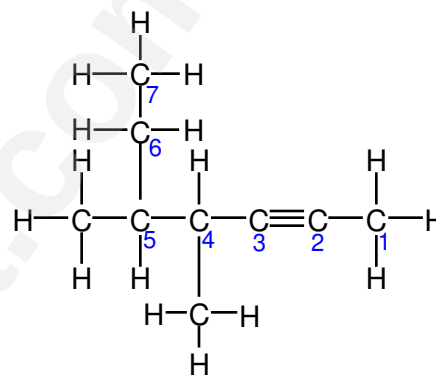
- An alkyne is a compound of carbon and hydrogen that **contains a carbon-carbon triple bond**.
- General formula: C_nH_{2n-2}
- Functional group: carbon-carbon triple bond
- Alkynes are **unsaturated hydrocarbons**.
Why hydrocarbons? They consist of hydrogen and carbon atoms only.
Why unsaturated? They have carbon-carbon triple bonds.

- The **first alkyne** in the homologous series, **ethyne** (acetylene, $\text{H}-\text{C}\equiv\text{C}-\text{H}$) is a colourless gas that burns in oxygen to form CO_2 and H_2O . The combustion of acetylene releases more energy per mole of product formed than any other hydrocarbons. It burns with a very hot flame and is an excellent fuel.

Example 3

The IUPAC name of the accompanying compound can be determined as follows:

- The compound is a hydrocarbon with a carbon-carbon triple bond – an alkyne. The name ends on *-yne*.
 - The longest chain containing the triple bond has 7 C atoms – the parent name is *hept-*.
 - Numbered from the other end of the chain, the triple bond is after C2. Numbered from the left, the triple bond is after C5. The former gives lower number.
 - Place the number -2- of the triple bond between the parent name and the suffix. Use a hyphen between the number and the suffix and between the number and the parent name.
 - The substituents, two *methyl* groups, are on C4 and C5.
- The compound is **4,5-dimethylhept-2-yne**.

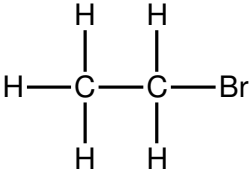
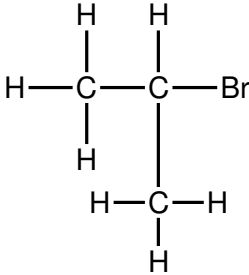
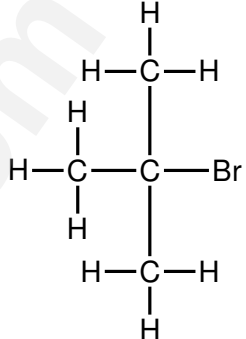


1.6.2 IUPAC names of other homologous series

(a) Haloalkanes

Fast facts

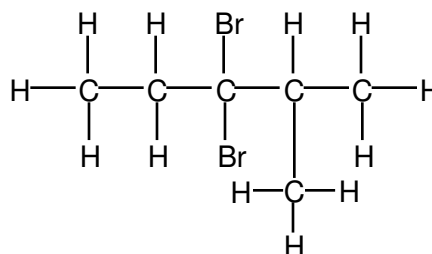
- A haloalkane (or an alkyl halide) is an organic compound in which **one or more H atoms in an alkane have been replaced with halogen atoms**.
- General formula: $\text{C}_n\text{H}_{2n+1}\text{X}$ ($\text{X} = \text{F}, \text{Cl}, \text{Br}$ or I)
- Functional group: a halogen bonded to a saturated C atom i.e. a C atom forming four single bonds
- Haloalkanes can be classified as primary, secondary or tertiary depending on the number of C atoms bonded to the carbon with the halogen.

Primary haloalkane	Secondary haloalkane	Tertiary haloalkane
One C atom is bonded to the C atom bonded to the halogen.	Two C atoms bonded to the C atom bonded to the halogen.	Three C atoms bonded to the C atom bonded to the halogen.
		

Example 4

The IUPAC name of the accompanying compound can be determined as follows:

- The compound is an alkane containing two halogen atoms – a haloalkane. The longest chain contains 5 C atoms - the parent name is *pentane*.
- Three substituents are present: a *methyl* group and two bromine atoms. Numbered from the left, the *methyl* group is on C4, and the Br atoms on C3. Numbered from the right, the *methyl* group is on C2, and the Br atoms on C3. The latter gives the lower numbers.
- Alphabetically *bromo* comes before *methyl*. The compound is **3,3-dibromo-2-methylpentane**.



(b) Alcohols

Fast facts

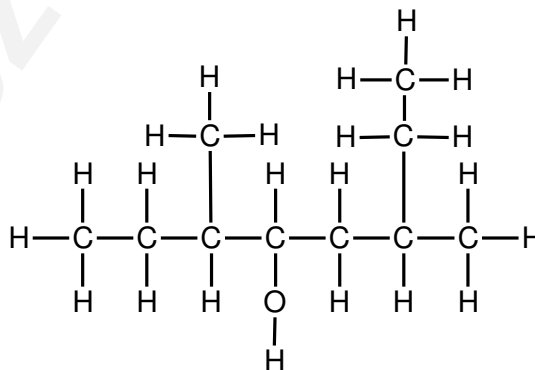
- An alcohol (or alkanol) is an organic compound in which **H atoms in an alkane have been substituted with hydroxyl groups (-OH groups)**.
- General formula: $C_nH_{2n+1}OH$
- Functional group: a hydroxyl group (- OH) bonded to a saturated C atom (sp^3 C atom)
- Alcohols are regarded as organic derivatives of water in which one H atom of water is replaced by an organic group.
- Methanol (CH_3OH) and ethanol (CH_3CH_2OH) are two of the most important industrial chemicals. Methanol is toxic to humans and causes blindness in small doses. Ethanol is, apart from numerous other industrial uses, used in alcoholic beverages.
- Alcohols can be classified as **primary, secondary or tertiary** depending on the number of C atoms bonded to the carbon atom containing the hydroxyl group.

Primary alcohol	Secondary alcohol	Tertiary alcohol
One C atom is bonded to the carbon bonded to hydroxyl group.	Two C atoms bonded to the carbon that is bonded to hydroxyl group.	Three C atoms bonded to carbon that is bonded to hydroxyl group
$ \begin{array}{c} \text{H} \quad \text{H} \\ \quad \\ \text{H}-\text{C}-\text{C}-\text{O}-\text{H} \\ \quad \\ \text{H} \quad \text{H} \end{array} $	$ \begin{array}{c} \text{H} \quad \text{H} \quad \text{H} \\ \quad \quad \\ \text{H}-\text{C}-\text{C}-\text{C}-\text{H} \\ \quad \quad \\ \text{H} \quad \text{O} \quad \text{H} \\ \quad \\ \quad \text{H} \end{array} $	$ \begin{array}{c} \text{H} \\ \\ \text{H}-\text{C}-\text{H} \\ \quad \quad \\ \text{H} \quad \text{C} \quad \text{H} \\ \quad \quad \\ \text{H}-\text{C}-\text{C}-\text{C}-\text{H} \\ \quad \quad \\ \text{H} \quad \text{O} \quad \text{H} \\ \quad \\ \quad \text{H} \end{array} $

Example 5

The IUPAC name of the accompanying compound can be determined as follows:

- The compound is an alkane containing a *hydroxyl* group – an alcohol. The suffix *-ol* replaces the *-e* in the corresponding alkane.
- The longest chain containing the hydroxyl group has 8 C atoms - the parent name is *oct-*.
- Numbered from the right, the *hydroxyl* group is on C5. Numbered from the left it is on C4. The latter gives the lower number. The number is written between the parent name and the suffix. Hyphens separate the number from the parent name and from the suffix i.e. octan-4-ol.
- Two substituents are present: two *methyl* groups on C3 and C6. The compound is **3,6-dimethyloctan-4-ol**.



(c) Aldehydes

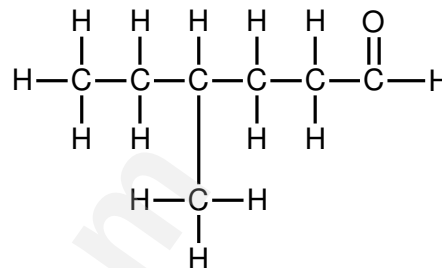
Fast facts

- Aldehydes are organic compounds having the general structure RCHO where R = H or alkyl.
- General formula: RCHO (R = alkyl group)
- Functional group: -CHO i.e. a carbonyl group ($>\text{C}=\text{O}$, pronounced car-bo-**neel**) with at least one H atom bonded to the carbonyl C atom. The -CHO group is called a formyl group.
- The **first aldehyde** in the homologous series, **methanal**, is an important industrial chemical. It is used in the production of many plastics. Its common name is **formaldehyde** and its aqueous solution is sold as formalin used as preservative for biological specimens.

Example 6

The IUPAC name of the accompanying compound can be determined as follows:

- The compound contains a -CHO group – an aldehyde. The suffix *-al* replaces the *-e* in the name of the corresponding alkane.
- The longest chain containing the -CHO group has 6 C atoms - the parent name is *hex-*. The compound is a *hexanal*.
- One substituent is present: a *methyl* group on C4 (the carbonyl C atom is always C1). The compound is **4-methylhexanal**.



(d) Ketones

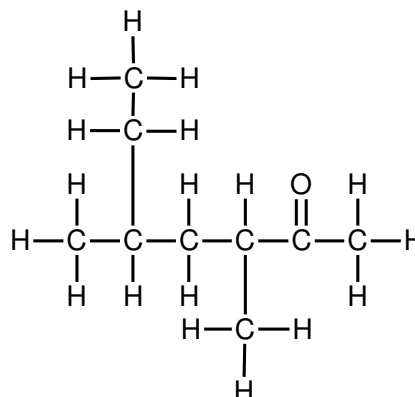
Fast facts

- Ketones are organic compounds with two alkyl groups (R and R') bonded to the carbon atom of a carbonyl group.
- General formula: RCOR' (R & R' = alkyl groups)
- Functional group: a carbonyl group ($>\text{C}=\text{O}$, pronounced car-bo-**neel**) with two alkyl groups bonded to it (keto group)
- The **third ketone** in the homologous series, **propan-2-one** (or just propanone), is well known as **acetone**. It is an industrial solvent.

Example 7

The IUPAC name of the accompanying compound can be determined as follows:

- The compound contains a RCOR' group – a ketone. The *-e* in the corresponding alkane is replaced with *-one*.
- The longest chain containing the carbonyl group has 7 C atoms - the parent name is *hept-*.
- Numbered from the left, the carbonyl C atom is C6. Numbered from the right it is C2. The latter gives the lower number. The number is written between the parent name and the suffix. Hyphens separate the number from the parent name and from the suffix, i.e. heptan-2-one.
- Two substituents are present: two *methyl* groups on C3 and C5.
- The compound is **3,5-dimethylheptan-2-one**.



(e) Carboxylic acids

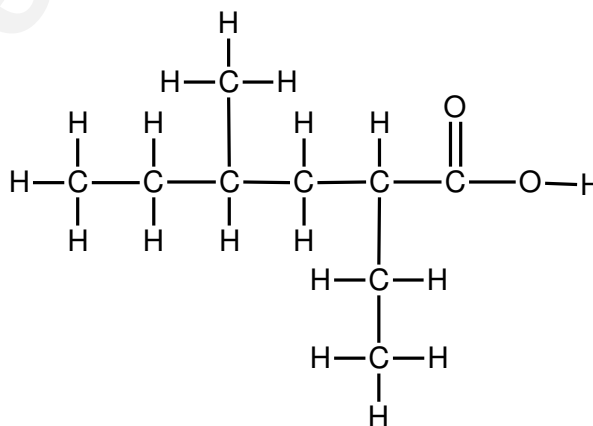
Fast facts

- A carboxylic acid is an organic compound containing a carboxyl group ($-\text{COOH}$ group). Carboxylic acids have the general structure RCOOH .
- General formula: $\text{C}_n\text{H}_{2n+1}\text{COOH}$ (or RCOOH)
- Functional group: a carboxyl group ($-\text{COOH}$) bonded to a saturated C atom (sp^3 C atom)
- Many carboxylic acids are found in nature. Methanoic acid (HCOOH), the first carboxylic acid in the homologous series, has a biting taste and is responsible for the sting of some ants. Ethanoic acid (CH_3COOH), the second carboxylic acid, is sour component of vinegar. Oxidation of ethanol to ethanoic acid causes “bad” wine to taste sour.

Example 8

The IUPAC name of the accompanying compound can be determined as follows:

- The compound contains a $-\text{COOH}$ group – a carboxylic acid. The suffix *-oic acid* replaces the -e in the corresponding alkane.
- The longest chain containing the carboxyl group has 6 C atoms – the parent name is *hex-*.
- Two substituents are present. The carboxyl C atom is always C1, but the number is not shown in the name. An ethyl group is on C2 and a methyl group on C4. Hyphens separate numbers and prefixes.



The compound is **2-ethyl-4-methylhexanoic acid**.

(f) Esters

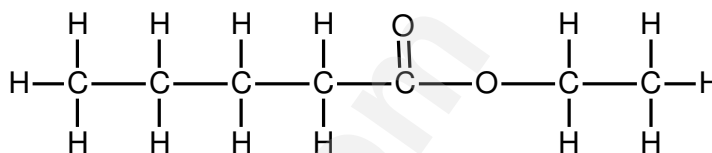
Fast facts

- An ester is an organic compound with the general structure RCOOR' ($\text{R} = \text{H}$ or alkyl group; $\text{R}' = \text{alkyl group}$).
- General formula: RCOOR'
- Functional group: $-\text{COOR}'$ ($\text{R}' = \text{alkyl group}$)
- Esters are derivatives of carboxylic acids and can be prepared by the reaction of an alcohol and a carboxylic acid.
- Many esters have pleasant and very characteristic odours.

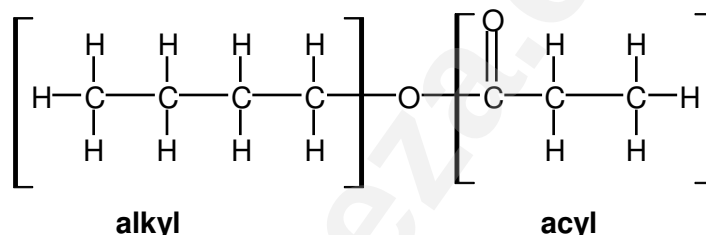
- The name of an ester has two parts: the first part comes from the alcohol and the last part from the carboxylic acid from which it is derived.

Example 9

The IUPAC name of the accompanying compound can be determined as follows:



- The compound contains a --COOR group – an ester.
- The ester has two groups, an alkyl and an acyl, that are named separately:



- The **alkyl group** (originally from butanol) has 4 C atoms. The parent alkane, butane, is changed to an alkyl group, i.e. *butyl*. This is the first part of the name of the ester.
- The **acyl group** (originally from propanoic acid) has 3 C atoms. The parent acid is propanoic acid. The *-ic* in the name is changed to *-ate*, i.e. propanoate. This is the second part of the name of the ester.
- The name of the compound is **butyl propanoate**.

Activity 1: Structure of organic compounds



Answer the questions below on your own. Compare your answers with those of your peers.

QUESTION 1

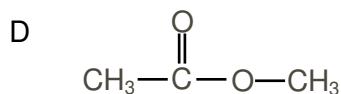
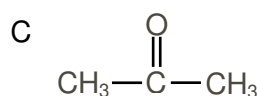
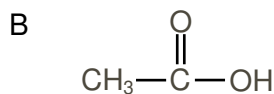
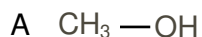
Give one word or term for each of the following statements.

- 1.1 Organic compounds with the functional group —OH
- 1.2 The homologous series to which propan-2-one belongs
- 1.3 The IUPAC name of the alkene with two carbon atoms
- 1.4 The homologous series to which the compound CH_3Cl belongs
- 1.5 The general term that describes compounds that consist of hydrogen and carbon atoms only
- 1.6 The homologous series to which $\text{H—C}\equiv\text{C—H}$ belongs
- 1.7 The IUPAC name of the first aldehyde in the homologous series
- 1.8 Atoms, groups of atoms or bonds that give a homologous series its characteristic properties
- 1.9 The IUPAC name of the first alkyne in the homologous series
- 1.10 The IUPAC name of the first ketone in the homologous series
- 1.11 A group of organic compounds with the carbonyl group as functional group
- 1.12 An atom or a group of atoms that gives an organic compound its chemical properties
- 1.13 Hydrocarbons containing triple bonds
- 1.14 Alkanes in which a hydrogen atom has been substituted by a halogen atom
- 1.15 Compounds with the same molecular formula but different structural formulae

QUESTION 2

Four options are provided as possible answers to the following questions. Each question has only ONE correct answer. Choose the answer and write only the letter (A–D) next to the question number.

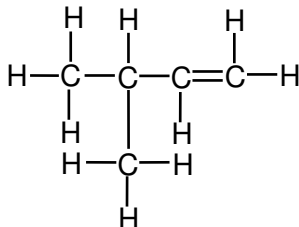
- 2.1 Which formula shown below represents a molecule of an ester?



2.2 Which ONE of the following CANNOT be an ester or a carboxylic acid?

- A C_3H_6O B $C_3H_4O_2$ C CH_2O_2 D $C_2H_4O_2$

2.3 Consider the organic compound represented below.



The compound is ...

- A saturated and branched.
B unsaturated and branched.
C saturated and straight-chained.
D unsaturated and straight-chained.

2.4 A structural isomer of butane is ...

- A propane. B 2-methylbutane.
C 2-methylpropane. D 2,2-dimethylpropane.

2.5 The alcohols form a homologous series. This means that alcohols have ...

- A similar chemical properties.
B similar physical properties.
C the same molecular formula.
D the same structural formula.

2.6 Which ONE of the following general formulae represents alkynes?

- A C_nH_{2n+2} B C_nH_{2n-2} C C_nH_{2n} D C_nH_{2n-1}

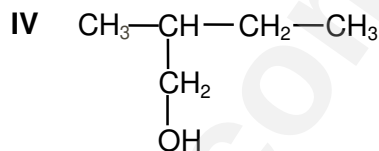
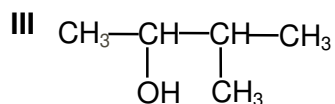
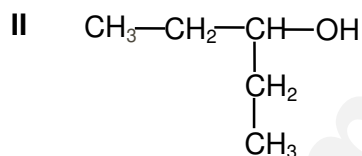
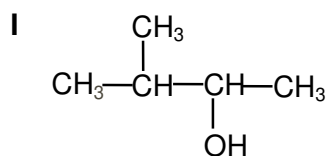
2.7 Which ONE of the following homologous series does NOT contain a CARBONYL group ($C=O$)?

- A Aldehydes B Alcohols
C Carboxylic acids D Esters

2.8 Which ONE of the following compounds CANNOT be an alkene?

- A C_2H_4 B C_3H_6 C C_3H_8 D C_4H_8

2.9 The structures of four organic compounds are shown below.

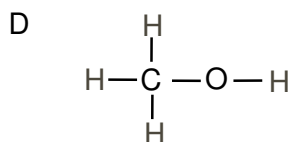
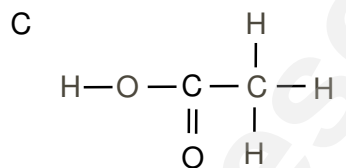
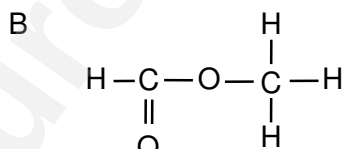
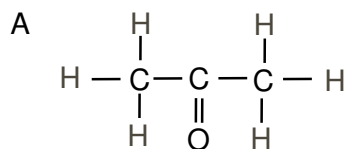


Which of the above compounds have the same IUPAC name?

- A I and II only
C I and III only

- B III and IV only
D II and IV only

2.10 Which ONE of the following compounds represents a ketone?



2.11 Consider the compound with molecular formula C_4H_{10} . How many structural isomers does this compound have?

- A 1 B 2 C 3 D 4

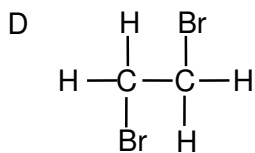
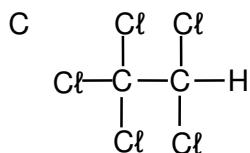
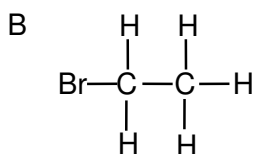
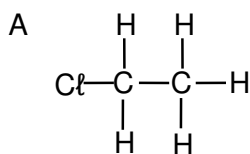
2.12 Which ONE of the following is an alkane?

- A C_8H_{16} B C_6H_{14} C C_7H_{10} D C_7H_{12}

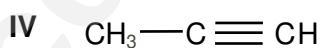
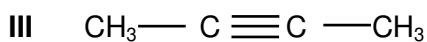
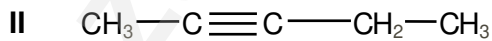
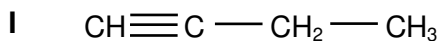
2.13 Which ONE of the following organic compounds is represented by the molecular formula $\text{C}_5\text{H}_{10}\text{O}_2$?

- A Ethyl ethanoate B Butyl ethanoate
C Ethyl propanoate D Propyl butanoate

2.14 Which ONE of the following compounds has structural isomers?



2.15 Consider the organic compounds (I to IV) shown below.



Which of the compounds above are structural isomers?

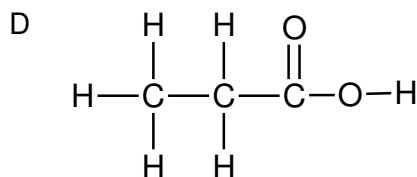
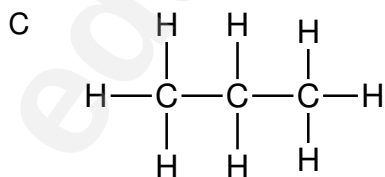
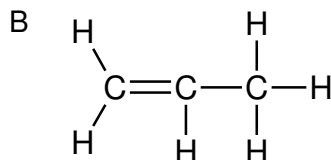
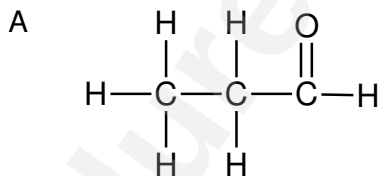
A I and II

B I and III

C I and IV

D II and III

2.16 Which ONE of the compounds represented below is an UNSATURATED hydrocarbon?



2.17 Which ONE of the following compounds is saturated?

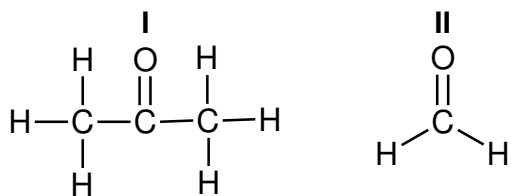
A C_4H_{10}

B C_5H_{10}

C $\text{C}_5\text{H}_9\text{OH}$

D C_6H_{10}

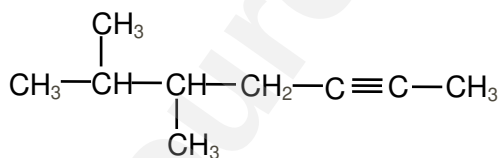
2.18 Consider the two organic compounds represented by I and II, as shown below.



Which ONE of the following correctly represents the homologous series to which each belongs?

	I	II
A	aldehyde	alcohol
B	ketone	alcohol
C	ketone	aldehyde
D	aldehyde	ketone

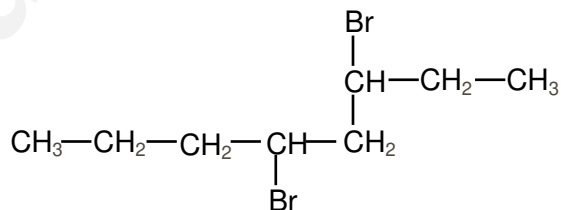
2.19 The structural formula of an organic compound is given below.



The IUPAC name of this compound is ...

- A 2,3-dimethylhept-5-yne. B 5,6-dimethylhept-2-yne.
 C 2,3-methylhept-2-yne. D 5,6-dimethylhept-3-yne.

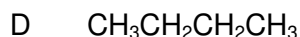
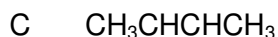
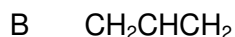
2.20 The condensed structural formula of an organic compound is shown below:



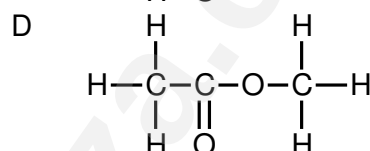
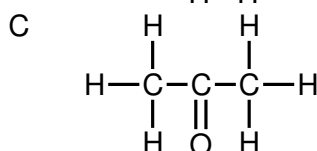
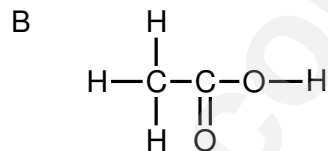
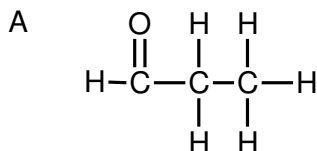
Which ONE of the following is the correct IUPAC name of this compound?

- A 4,6-dibromooctane B 4-bromo-5-bromo-5-propylpentane
 C 3,5-dibromooctane D 2-bromo-1-bromo-1-propylpentane

2.21 Which ONE of the following compounds belongs to the same homologous series as but-2-yne?



2.22 Which ONE of the following compounds is an isomer of $\text{CH}_3\text{CH}_2\text{COOH}$?



2.23 When the group $\begin{array}{c} \text{O} \\ || \\ -\text{C}-\text{O}- \end{array}$ is present in a compound, the compound may be ...

A propanal.

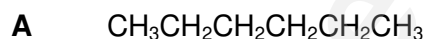
B 1-propanol.

C propan-2-one.

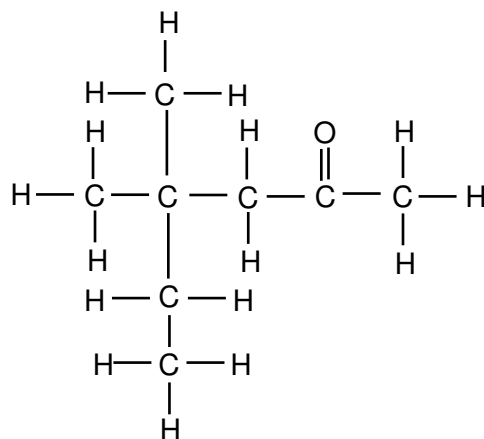
D methyl ethanoate

QUESTION 3

Consider the organic compounds labelled **A – C**.



B



3.1 To which homologous series does compound **C** belong?

3.2 Compound **C** reacts with chlorine gas in an inert solvent. Using structural formulae, write a balanced equation for the reaction that takes place.

3.3 Write down the IUPAC name for compound **B**.

3.4 Write down the structural formula of an isomer of compound **A** that has only FOUR carbon atoms in the longest chain.

QUESTION 4

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

A	$\text{CH}\equiv\text{C}-\text{CH}_2-\text{CH}_2-\text{CH}_3$	B	$\text{CH}_3\text{CH}_2\text{CH}_2\underset{\text{OH}}{\text{CH}}\text{CH}_3$
C	$\begin{array}{c} \text{CH}_2=\text{C}-\text{CH}_2 \\ \\ \text{CH}_3 \end{array}$	D	Pentanoic acid
E	$\begin{array}{ccccccc} & \text{H} & & \text{H} & & \text{H} & & \text{O} \\ & & & & & & & \\ \text{H} & -\text{C} & - & \text{C} & - & \text{C} & - & \text{C} & - & \text{H} \\ & & & & & & & & & \\ & \text{H} & & \text{H} & - & \text{C} & - & \text{H} & & \text{H} \\ & & & & & & & & & \\ & & & & & \text{H} & & & & \end{array}$	F	$\text{CH}_3-\text{CH}_2-\text{O}-\overset{\text{O}}{\underset{ }{\text{C}}}-\text{CH}_2-\text{CH}_3$

4.1 Write down the letter(s) that represent(s) each of the following:

- 4.1.1 An alkyne
- 4.1.2 Two compounds that are structural isomers
- 4.1.3 A compound containing a carboxyl group
- 4.1.4 An aldehyde
- 4.1.5 An alcohol

4.2 Write down the:

- 4.2.1 IUPAC name of compound **C**
- 4.2.2 Structural formula of compound **D**

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

- 4.3.1 How can one quickly establish whether compound **F** is indeed being formed?
- 4.3.2 Write down the IUPAC name of the alcohol needed to prepare compound **F**.
- 4.3.3 Write down the IUPAC name of compound **F**.

QUESTION 5

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

A <pre> H H H H O H - C - C - C - C - C - H H C H H H </pre>	B <pre> H H - C ≡ C - C - H H </pre>
C <pre> H O H H - C - C - C - H H H </pre>	D <pre> H H H H H - C - C - C - C - H H H H H </pre>
E <pre> CH₃ CH₃ - CH - CH₂ - CH - CH₂ - CH₃ CH₃ </pre>	F ethyl butanoate

5.1 Write down the letter that represents the following:

5.1.1 A ketone

5.1.2 A compound which is an isomer of methylpropane

5.2 Write down the IUPAC name of the following:

5.2.1 Compound **A**

5.2.2 Compound **B**

5.2.3 **E**

5.3 Write down the NAME or FORMULA of EACH of the TWO products formed during the complete combustion of compound **D**.

5.4 Compound **F** is the organic product of the reaction between a carboxylic acid and ethanol. Write down the following:

5.4.1 The name of the homologous series to which compound **F** belongs

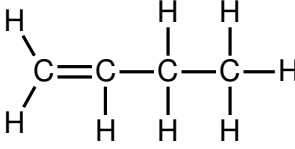
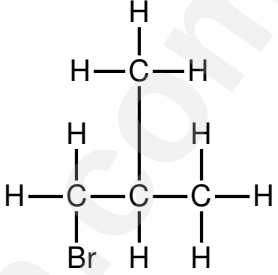
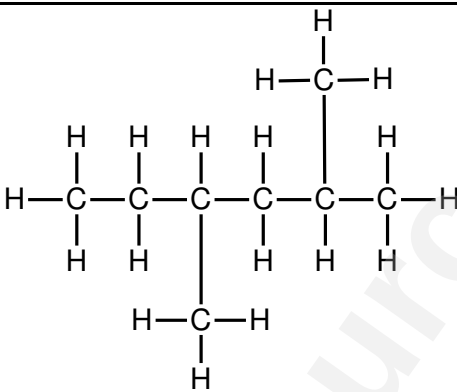
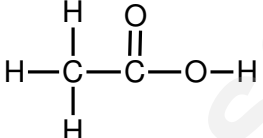
5.4.2 The structural formula of the FUNCTIONAL GROUP of carboxylic acids

5.4.3 The IUPAC name of the carboxylic acid from which compound **F** is prepared

5.4.4 The structural formula of compound **F**

QUESTION 6

The chemical properties of organic compounds are determined by their functional groups. The letters **A** to **F** in the table below represent six organic compounds.

A		B	
C		D	Methanal
E		F	Methyl methanoate

6.1 Write down the LETTER that represents the following:

6.1.1 An alkene

6.1.2 An aldehyde

6.2 Write down the IUPAC name of the following:

6.2.1 Compound **B**

6.2.2 Compound **C**

6.3 Write down the structural formula of compound **D**.

6.4 Write down the IUPAC name of the carboxylic acid shown in the table.

6.5 Write down the structural formula of compound **F**.

QUESTION 7

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

A	Pent-2-ene	B	
C	Propyl methanoate	D	2,5-dimethylheptane
E		F	

7.1 Write down the letter representing the compound which:

7.1.1 Is an aldehyde

7.1.2 Has the general formula C_nH_{2n}

7.1.3 Is unsaturated

7.1.4 Is a ketone

7.1.5 Is a hydrocarbon

7.1.6 Can be prepared by the reaction of an alcohol with a carboxylic acid

7.2 Write down the structural formula of:

7.2.1 Compound **A**

7.2.2 Compound **D**

7.3 Write down the:

7.3.1 NAME of the functional group of compound **F**

7.3.2 IUPAC name of compound **B**

QUESTION 8

Millions of organic compounds are known to date. Four of these compounds, represented by the letters **P**, **Q**, **R** and **S**, are shown in the table below.

P	methanal	Q	$ \begin{array}{ccccccc} & \text{H} & & \text{H} & & \text{O} & & \text{H} \\ & & & & & & & \\ \text{H} & - \text{C} & - & \text{C} & - & \text{C} & - & \text{C} & - \text{H} \\ & & & & & & & \\ & \text{H} & & \text{H} & & & & \text{H} \end{array} $
R	$ \begin{array}{ccccccc} & & & & \text{H} & & \\ & & & & & & \\ & & & & \text{H} - \text{C} - \text{H} & & \\ & & & & & & \\ \text{H} & & \text{H} & & & & \text{H} \\ & & & & & & \\ \text{H} - \text{C} - & \text{C} & - \text{C} = \text{C} - & \text{C} & - & \text{C} & - \text{H} \\ & & & & & & \\ \text{H} & & \text{H} & & \text{H} & & \text{H} \\ & & & & & & \\ & & \text{H} - \text{C} - \text{H} & & & & \\ & & & & & & \\ & & \text{H} & & & & \end{array} $	S	$ \begin{array}{ccccccc} & & & & \text{H} & & \\ & & & & & & \\ & & & & \text{H} - \text{C} - \text{H} & & \\ & & & & & & \\ \text{H} & & \text{H} & & \text{H} & & \text{H} \\ & & & & & & \\ \text{H} - \text{C} - & \text{C} & - \text{C} & - & \text{C} & - & \text{H} \\ & & & & & & \\ \text{H} & & \text{O} & & \text{H} & & \text{H} \\ & & & & & & \\ & & \text{H} & & & & \end{array} $

8.1 Write down the following:

8.1.1 Structural formula of the functional group of compound **P**

8.1.2 Homologous series to which compound **Q** belongs

8.1.3 Structural formula of a straight chain functional isomer of compound **Q**

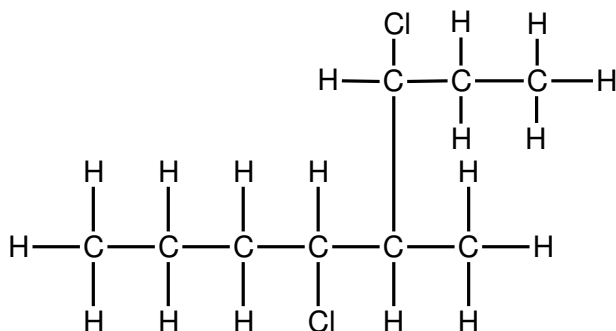
8.1.4 IUPAC name of compound **R**

8.2 Compound **S** represents an alcohol. Classify this alcohol as primary, secondary or tertiary.

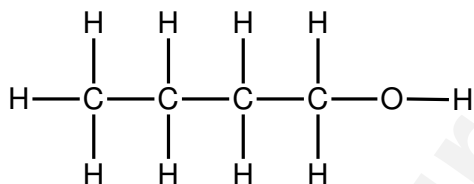
QUESTION 9

Consider the organic compounds represented by the letters **A** to **C** below.

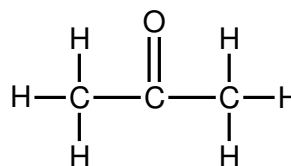
A



B



C



9.1 Write down the:

9.1.1 Name of the homologous series to which compound **C** belongs

9.1.2 IUPAC name of compound **A**

9.1.3 Structural formula of a tertiary alcohol that is a structural isomer of compound **B**

9.2 An alcohol and methanoic acid are heated in the presence of concentrated sulphuric acid to form an ester.

9.2.1 What is the role of the concentrated sulphuric acid in this reaction?

9.2.2 Write down the NAME or FORMULA of the inorganic product formed.

The ester contains 6,67% hydrogen (H), 40% carbon (C) and 53,33% oxygen (O). The molar mass of the ester is $60 \text{ g} \cdot \text{mol}^{-1}$.

Use a calculation to determine its:

9.2.3 Empirical

9.2.4 Molecular formula

Write down the:

9.2.5 Structural formula of methanoic acid

9.2.6 IUPAC name of the ester

QUESTION 10

The letters **A** to **D** in the table below represent four organic compounds.

A	$\begin{array}{ccccccc} & \text{H} & & \text{CH}_3 & \text{H} & & \text{H} \\ & & & & & & \\ \text{H} & - \text{C} & - & \text{C} & - & \text{C} & - \text{C} \equiv \text{C} - \text{C} - \text{H} \\ & & & & & & \\ & \text{CH}_3 & & \text{H} & \text{CH}_2\text{CH}_3 & & \text{H} \end{array}$	B	$\begin{array}{ccccccc} & \text{H} & & \text{H} & & \text{O} & & \text{H} \\ & & & & & & & \\ \text{H} & - \text{C} & - & \text{C} & - & \text{C} & - & \text{C} - \text{H} \\ & & & & & & & \\ & \text{H} & & \text{H} & & & & \text{H} \end{array}$
C	$\text{CH}_3\text{CH}_2\text{CHO}$	D	Butane

Use the information in the table to answer the questions that follow.

10.1 Write down the:

10.1.1 Letter that represents a ketone

10.1.2 Structural formula of the functional group of compound **C**

10.1.3 General formula of the homologous series to which compound **A** belongs

10.1.4 IUPAC name of compound **A**

10.1.5 IUPAC name of compound **B**

10.2 Compound **D** is a gas used in cigarette lighters.

10.2.1 To which homologous series does compound **D** belong?

10.2.2 Write down the STRUCTURAL FORMULA and IUPAC NAME of a structural isomer of compound **D**.

10.2.3 Is the isomer in QUESTION 10.2.2 a CHAIN, POSITIONAL or FUNCTIONAL isomer?

10.3 Compound **D** reacts with bromine (Br_2) to form 2-bromobutane.

Write down the name of the:

10.3.1 Homologous series to which 2-bromobutane belongs

10.3.2 Type of reaction that takes place

4. UNIT 2: Physical Properties



2.1 Types of physical properties

The physical properties of organic compounds that will be studied in this section are defined in the table below.

Physical property	Definition
Boiling point	The temperature at which the vapour pressure of a liquid equals atmospheric pressure.
Melting point	The temperature at which the solid and liquid phases of a substance are at equilibrium.
Vapour pressure	The pressure exerted by a vapour at equilibrium with its liquid in a closed system.

Physical properties of organic compounds are **mainly determined by the strength of intermolecular forces**.

2.2 Types of intermolecular forces

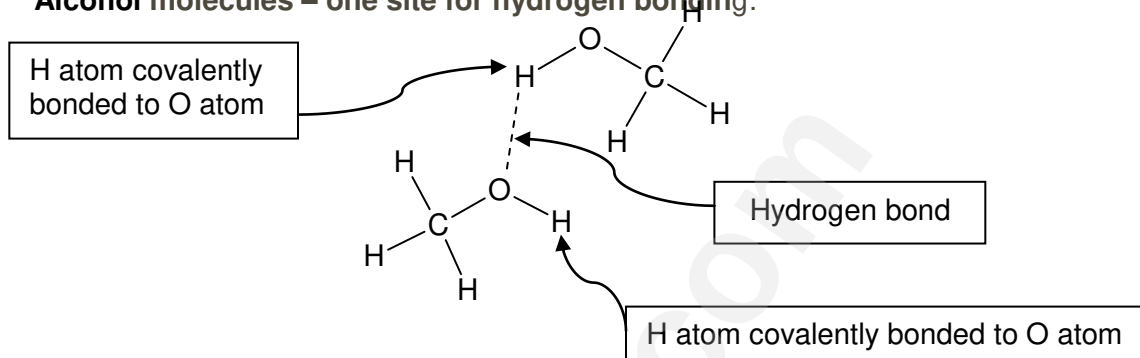
Intermolecular forces are the interactions that exist between molecules. The three different types of intermolecular forces that can exist between organic molecules are, in order of increasing strength:

- **London (or dispersion) forces** – weakest intermolecular force. These forces are present between all molecules.
- **Dipole-dipole forces** – present between polar molecules
- **Hydrogen bonding** - strongest intermolecular force. Only between molecules in which an H atom is covalently bonded to a N, O or F atom.

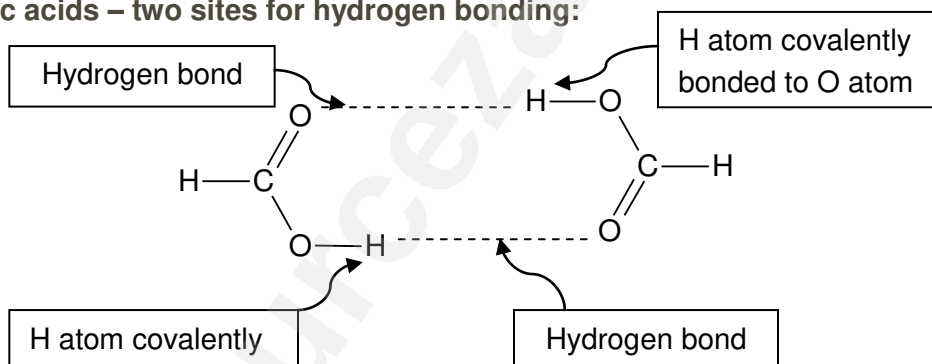
For our purposes: Only between molecules of alcohols and molecules of carboxylic acids.

Examples:

Alcohol molecules – one site for hydrogen bonding:



Carboxylic acids – two sites for hydrogen bonding:



The table below links the homologous series discussed in this manual to the type of intermolecular forces that can be found between molecules in each.

Homologous series	Alkanes Alkenes Alkynes	Aldehydes Ketones Haloalkanes	Alcohols Carboxylic acids
Type of intermolecular forces	London forces	London forces Dipole-dipole forces	London forces Dipole-dipole forces Hydrogen bonding

1.3 Physical properties and intermolecular forces

- Physical properties of compounds depend on the **strength of intermolecular forces** (forces between molecules).
- Stronger intermolecular forces** results in:
 - Higher** boiling points
 - Higher** melting points
 - Lower** vapour pressures
- Compounds with **high boiling points** have **low vapour pressures**.

1.3.1 Boiling point

Boiling point of organic compounds **increase with increase in strength of intermolecular forces** - more energy needed to overcome the intermolecular forces.

The boiling point of substances depends on:

(a) **Type of functional group**

Molecules have **different degrees of polarity as determined by the type of functional group** present. The polarity ranking of functional groups discussed in this document is as follows:

Polarity ranking of functional groups:

Carboxylic acid > Alcohol > Ketone ~ Aldehyde > Ester > Alkane

Principle: The greater the polarity of molecules, the greater the forces of attraction between molecules, and the higher the boiling point.

(b) **Surface area – chain length**

For compounds with the **same functional group**, the **longer the carbon chain**, the **larger the surface area** and the **higher the boiling point**.

(c) **Surface area – branching**

For compounds with the **same functional group** and **comparable molecular mass**, **increase in branching** results in a **decrease in surface area**, **weaker intermolecular forces** and thus a **decrease in boiling point**.

1.3.2 Vapour pressure

Compounds with **HIGH BOILING POINTS** have **LOW VAPOUR PRESSURES**. Vapour pressure decreases with increase in strength of intermolecular forces.

Vapour pressure is affected by:

(a) **Type of functional group**

For compounds of **comparable molecular mass**, the **more polar the functional group**, the **stronger the intermolecular forces** and the **LOWER** the vapour pressure.

(b) **Surface area – chain length**

For compounds with the **same functional group**, the **longer the carbon chain**, the **larger the surface area** and the **lower the vapour pressure**. A larger surface area has more sites where London forces can form, resulting in stronger intermolecular forces, and thus a lower vapour pressure.

(c) **Surface area – branching**

For compounds with the **same functional group** and of **comparable molecular mass**, **increase in branching** results in a **decrease in surface area**, **weaker intermolecular forces** and thus **an increase in vapour pressure**.

1.3.3 Melting points

Melting points are affected by:

(a) **Type of functional group**

The polarity of molecules determines the forces of attraction between the molecules in the solid state. For compounds of **comparable molecular mass**, the **more polar the functional group**, the **stronger the intermolecular forces**, and the **higher the melting point**.

(b) **Surface area – chain length**

For compounds with the **same functional group**, the **longer the carbon chain**, the **larger the surface area** and the **higher the melting point**. A larger surface area has more sites where London forces can form. The combined effect of all the London forces result in stronger intermolecular forces and a higher melting point.

Activity 2: Physical properties of organic compounds



Answer the following questions in pairs.

QUESTION 1

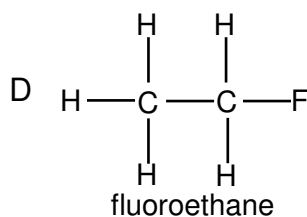
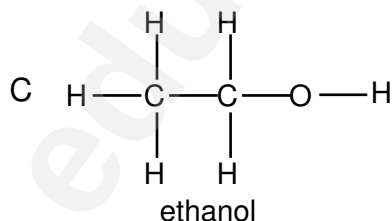
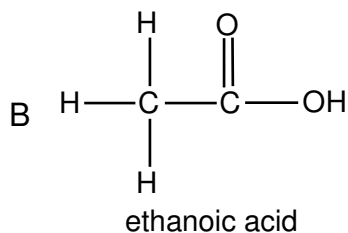
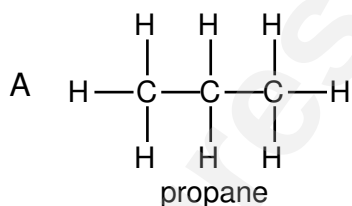
Give one word or term for each of the following statements.

- 1.1 The temperature at which the vapour pressure of a liquid equals atmospheric pressure
- 1.2 The pressure at which the vapour of a substance is in dynamic equilibrium with its liquid or solid form
- 1.3 The forces between molecules
- 1.4 The type of intermolecular force formed between molecules of alkanes

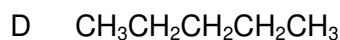
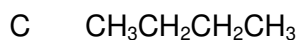
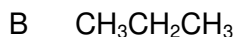
QUESTION 2

Four options are provided as possible answers to the following questions. Each question has only ONE correct answer. Choose the answer and write only the letter (A–D) next to the question number.

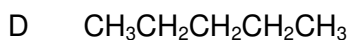
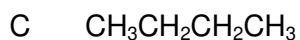
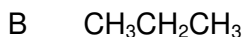
- 2.1 Which ONE of the compounds shown below has the highest vapour pressure at room temperature?



- 2.2 Which ONE of the following compounds has the highest melting point?



- 2.3 Which ONE of the following compounds has the highest boiling point?



2.4 Which ONE of the following compounds has the highest boiling point?

A	$\text{CH}_3\text{---CH}_2\text{---CH}_2\text{---CH}_2\text{---CH}_2\text{---CH}_3$
B	$\begin{array}{ccccccc}\text{CH}_3 & \text{---} & \text{CH}_2 & \text{---} & \text{CH} & \text{---} & \text{CH}_2 & \text{---} & \text{CH}_3 \\ & & & & & & & & \\ & & & & \text{CH}_3 & & & & \end{array}$
C	$\begin{array}{ccccccc}\text{CH}_3 & \text{---} & \text{CH} & \text{---} & \text{CH} & \text{---} & \text{CH}_3 \\ & & & & & & \\ & & \text{CH}_3 & & \text{CH}_3 & & \end{array}$
D	$\begin{array}{ccccccc} & & \text{CH}_3 & & & & \\ & & & & & & \\ \text{CH}_3 & \text{---} & \text{C} & \text{---} & \text{CH}_2 & \text{---} & \text{CH}_3 \\ & & & & & & \\ & & \text{CH}_3 & & & & \end{array}$

2.5 Which ONE of the following compounds has dipole-dipole forces between its molecules?

A Ethanal

B Ethane

C Ethene

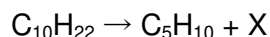
D Ethyne

QUESTION 3

In the petroleum industry smaller, more useful hydrocarbons are obtained from larger ones by a process called cracking.

3.1.1 Define the term *hydrocarbon*.

The compound $\text{C}_{10}\text{H}_{22}$ is cracked to obtain alkane X and another hydrocarbon. The cracking reaction is represented by the following incomplete equation:



3.1.2 Write down the molecular formula of compound X.

The cracking process requires very high temperatures. Therefore engineers use a catalyst in the reaction.

3.1.3 Give TWO reasons why they use a catalyst.

2-methylbut-1-ene (C_5H_{10}) is one of the compounds formed in this reaction.

3.1.4 Write down the structural formula of 2-methylbut-1-ene.

3.1.5 Name the type of reaction that occurs when 2-methylbut-1-ene reacts with hydrogen.

QUESTION 4

Consider the structural isomers represented by **A**, **B** and **C** shown below.

	COMPOUND	BOILING POINT (°C)
A	$\text{CH}_3 - \text{CH}_2 - \text{CH}_2 - \text{CH}_2 - \text{CH}_3$	36
B	$\begin{array}{c} \text{CH}_3 - \text{CH}_2 - \text{CH} - \text{CH}_3 \\ \\ \text{CH}_3 \end{array}$	28
C	$\begin{array}{c} \text{CH}_3 \\ \\ \text{CH}_3 - \text{C} - \text{CH}_3 \\ \\ \text{CH}_3 \end{array}$	9

- 4.1 Give a reason why the above compounds are considered to be structural isomers.
- 4.2 Describe the trend in the boiling points from **A** to **C**, as shown in the table. Explain this trend by referring to molecular structure, strength of intermolecular forces and energy involved.
- 4.3 Give a reason why branched hydrocarbons are preferred to straight chain hydrocarbons as fuel.

QUESTION 5

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

- 5.1 Write down the:
- 5.1.1 Most important use of the alkanes in the above table
- 5.1.2 General formula of the alkanes

Refer to the table to answer the following questions.

5.2 For this investigation, write down the following:

5.2.1 Dependent variable

5.2.2 Independent variable

5.2.3 Conclusion that can be drawn from the above results

5.3 Write down the NAME of an alkane that is a liquid at 25 °C.

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

5.5 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.

QUESTION 6

The table below shows the boiling points of four organic compounds, represented by the letters **A** to **D**, of comparable molecular mass.

Compound		Molecular mass	Boiling point (°C)
A	Butane	58	0
B	Propanal	58	49
C	Propan-1-ol	60	97
D	Ethanoic acid	60	118

6.1 Compound **A** is used as a fuel in gas burners.

6.1.1 Is compound **A** in the GAS, LIQUID or SOLID phase at 25 °C?

6.1.2 How will the boiling point of an ISOMER of compound **A** compare to that of compound **A**? Write down HIGHER THAN, LOWER THAN or EQUAL TO. Refer to MOLECULAR STRUCTURE, INTERMOLECULAR FORCES and the ENERGY needed to explain the answer.

6.1.3 Using molecular formulae, write down the balanced equation for the combustion of compound **A** in excess oxygen.

6.1.4 Compound **A** has a lower boiling point than compound **B**. Give reasons for this difference in boiling points by referring to the following:

- Structural differences between the two compounds
- Polarity
- Type and strength of intermolecular forces

6.2 Consider the boiling points of compounds **C** and **D**.

6.2.1 Give a reason for this difference in boiling points by referring to the TYPE intermolecular forces present in EACH of these compounds.

6.2.2 Which ONE of compound **C** or **D** has a higher vapour pressure? Refer to their boiling points to give a reason for the answer.

QUESTION 7

Three hydrocarbons (**A**, **B** and **C**) with molecular formula C_5H_{12} are used to investigate the effect of BRANCHING on the BOILING POINTS of hydrocarbons. The results obtained are shown in the table below.

HYDROCARBON	BOILING POINT (°C)
A	36
B	28
C	10

7.1 Write down the term used to describe compounds with the same molecular formula, but with different structural formulae.

7.2 Write down for this investigation the following:

7.2.1 Dependent variable

7.2.2 Independent variable

7.2.3 Controlled variable

7.3 Are these hydrocarbons saturated or unsaturated? Explain the answer.

7.4 One of the hydrocarbons (**A**, **B** or **C**) has a straight chain with no branches. Write down the following:

7.4.1 The letter (**A**, **B** or **C**) that represents this hydrocarbon

7.4.2 Its IUPAC name

7.5 Consider hydrocarbon **C** and its boiling point.

7.5.1 Write down the structural formula of hydrocarbon **C**.

7.5.2 Explain why hydrocarbon **C** has the lowest boiling point. In your explanation, refer to its structure, intermolecular forces and the energy involved.

7.6 Which ONE of hydrocarbons (**A**, **B** or **C**) has the highest vapour pressure? Refer to the data in the table to give a reason for the answer.

QUESTION 8

The table below shows five organic compounds represented by the letters **A** to **E**.

A	CH ₄
B	CH ₃ CH ₃
C	CH ₃ CH ₂ CH ₃
D	CH ₃ CH ₂ CH ₂ CH ₃
E	CH ₃ CH ₂ OH

8.1 Is compound **B** SATURATED or UNSATURATED? Give a reason for the answer.

Consider the boiling points of compounds **A** to **E** given in random order below and use them, where applicable, to answer the questions that follow.

0 °C	- 162 °C	- 42 °C	- 89 °C	78 °C
------	----------	---------	---------	-------

8.2 Write down the boiling point of:

8.2.1 Compound **C**

8.2.2 Compound **E**

8.3 Explain the difference in boiling points of compounds **C** and **E** by referring to the TYPE of intermolecular forces present in EACH of these compounds.

8.4 Does vapour pressure INCREASE or DECREASE from compounds **A** to **D**? Fully explain the answer.

8.5 How will the vapour pressure of 2-methylpropane compare to the vapour pressure of compound **D**? Write down only HIGHER THAN, LOWER THAN or EQUAL TO.

QUESTION 9

Four compounds of comparable molecular mass are used to investigate the effect of functional groups on vapour pressure. The results obtained are shown in the table below.

	COMPOUND	VAPOUR PRESSURE (kPa at 20 °C)
A	Butane	204
B	Propan-2-one	24,6

C	Propan-1-ol	2
D	Ethanoic acid	1,6

- 9.1 Define the term *functional group* of an organic compound.
- 9.2 Which ONE of the compounds (**A**, **B**, **C** or **D**) in the table has the:
- 9.2.1 Highest boiling point
(Refer to the vapour pressures in the table to give a reason for the answer.)
- 9.2.2 Weakest intermolecular forces
- 9.3 Refer to the type of intermolecular forces to explain the difference between the vapour pressure of compound **A** and compound **B**.
- 9.4 The vapour pressures of compounds **C** and **D** are much lower than those of compounds **A** and **B**. Name the type of intermolecular force in **C** and **D** that is responsible for this difference.
- 9.5 Briefly explain the difference in vapour pressure between compound **C** and compound **D**.
- 9.6 During a combustion reaction in a closed container of adjustable volume, 8 cm³ of compound A (butane) reacts in excess oxygen according to the following balanced equation: $2\text{C}_4\text{H}_{10}(\text{g}) + 13\text{O}_2(\text{g}) \rightarrow 8\text{CO}_2(\text{g}) + 10\text{H}_2\text{O}(\text{g})$
If the initial volume of the oxygen in the container was 60 cm³, calculate the TOTAL volume of the gases that are present in the container at the end of the reaction. All the gases in the container are at the same temperature and pressure.

QUESTION 10

The first six members of the alkanes occur as gases and liquids at normal temperatures. Alkanes are currently our most important fuels, but the use of alcohols as renewable energy source is becoming more and more important. Alcohols are liquids that might be a solution to the energy crisis.

- 10.1 Which chemical property of alkanes and alcohols make them suitable to be used as fuels?
- 10.2 The table shows the boiling points of the first six alkanes and the first six alcohols.

Alkane	Boiling point (°C)	Alcohol	Boiling point (°C)
methane	- 164	methanol	65
ethane	- 89	ethanol	79
propane	- 42	1-propanol	97
butane	- 0,5	1-butanol	117
pentane	36	1-pentanol	138
hexane	69	1-hexanol	156

- Draw a graph of boiling points versus number of carbon atoms for the first six ALCOHOLS. Choose 50 °C and 1 carbon atom as origin and use an appropriate scale. Plot the points and draw the best curve through the points.
- 10.3 What trend in boiling point can be observed from the graph?
 - 10.4 Provide a reason for the trend mentioned in QUESTION 10.3 by referring to the type of intermolecular forces.
 - 10.5 Explain, referring to the TYPE OF INTERMOLECULAR FORCES, why the boiling points of alcohols are higher than the boiling points of alkanes.
 - 10.6 People are always cautioned to keep liquids such as petrol (a mixture of alkanes) out of reach of children. Use the boiling points of alkanes and justify this precaution.
 - 10.7 Briefly explain why ethanol is a renewable energy source, while the alkanes are non-renewable.

Question 11

Four compounds of comparable molecular mass are used to investigate the effect of functional groups on vapour pressure. The results obtained are shown in the table below.

	COMPOUND	VAPOUR PRESSURE (kPa at 20 °C)
A	Butane	204
B	Propan-2-one	24,6
C	Propan-1-ol	2
D	Ethanoic acid	1,6

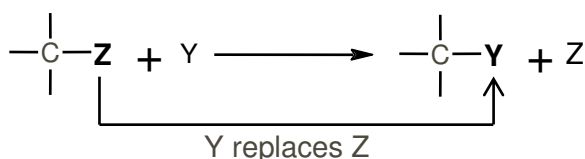
- 11.1 Define the term functional group of an organic compound.
- 11.2 Which ONE of the compounds (**A**, **B**, **C** or **D**) in the table has the:
 - 11.2.1 Highest boiling point
(Refer to the vapour pressures in the table to give a reason for the answer.)
 - 11.2.2 Weakest intermolecular forces
- 11.3 Refer to the type of intermolecular forces to explain the difference between the vapour pressure of compound **A** and compound **B**.
- 11.4 The vapour pressures of compounds **C** and **D** are much lower than those of compounds **A** and **B**. Name the type of intermolecular force in **A** and **B** that is responsible for this difference.
- 11.5 Briefly explain the difference in vapour pressure between compound **C** and compound **D**.
- 6.6 During a combustion reaction in a closed container of adjustable volume, 8 cm³ of compound **A** (butane) reacts in excess oxygen according to the following balanced equation: $2\text{C}_4\text{H}_{10}(\text{g}) + 13\text{O}_2(\text{g}) \rightarrow 8\text{CO}_2(\text{g}) + 10\text{H}_2\text{O}(\text{g})$
If the initial volume of the oxygen in the container was 60 cm³, calculate the TOTAL volume of the gases that are present in the container at the end of the reaction. All the gases in the container are at the same temperature and pressure.



1 UNIT 3: Reactions of organic compounds

Substitution reactions

Substitution is a reaction in which an atom or a group of atoms in a molecule is replaced by another atom or group of atoms.

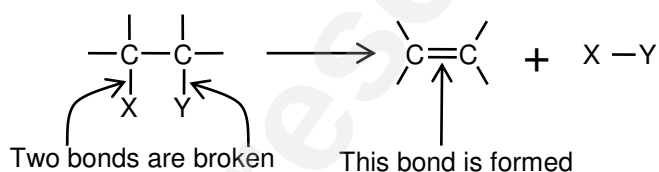


Substitution reactions involve the breaking of a bond between a C atom and another atom and the formation of a new bond between this C atom and another atom.

Elimination reactions

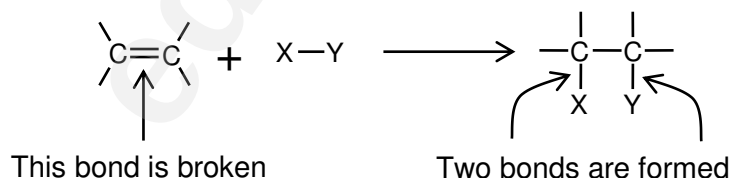
Elimination is a reaction in which elements of the starting material are “lost” and an additional bond is formed.

Two groups, X and Y, are removed from the starting material. Two bonds are broken and a new bond is formed between adjacent atoms, resulting in a double bond between the two atoms.



Addition reactions

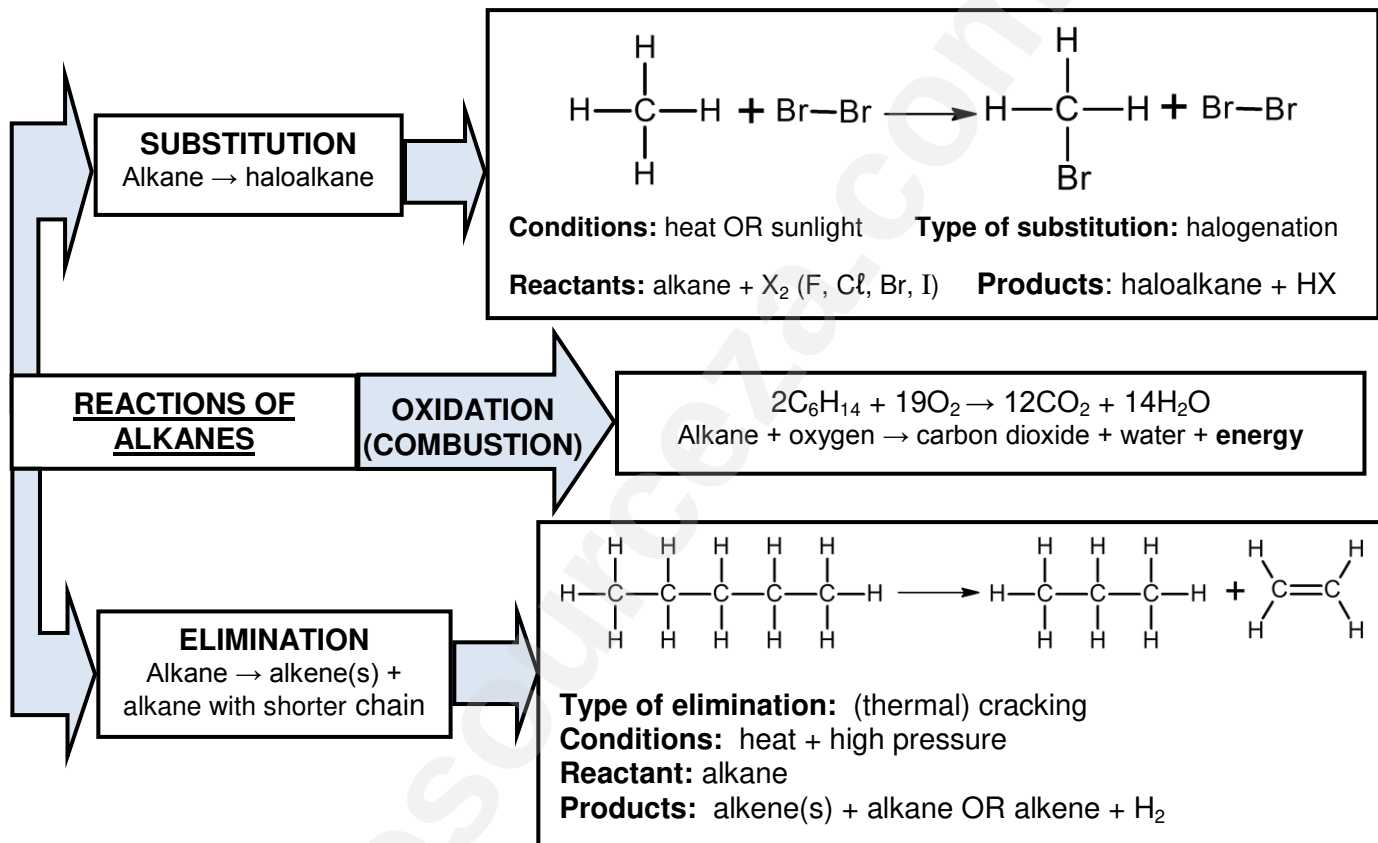
Addition is a reaction in which elements are added to a starting material.



Two groups, X and Y, are added to the starting material. A double bond is broken and two single bonds are formed. Addition and elimination reactions are exactly opposite. During elimination a double bond is formed and during an addition reaction a double bond is broken.

3.1 Reactions of alkanes

Due to their non-polar nature, alkanes are inert compounds. They are saturated hydrocarbons and cannot undergo addition reactions. They can only undergo substitution and elimination reactions. The reactions of alkanes are summarised in the mind map below.

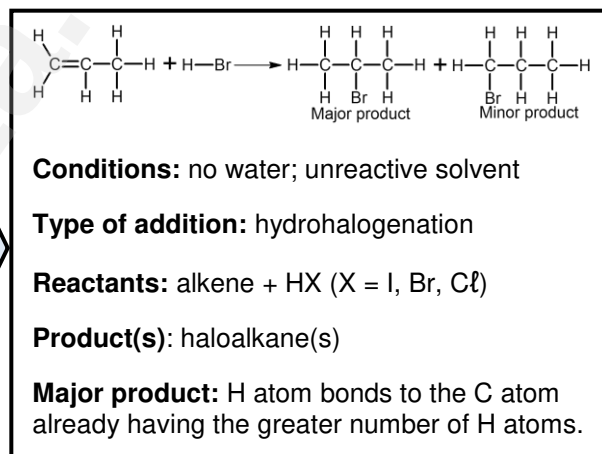
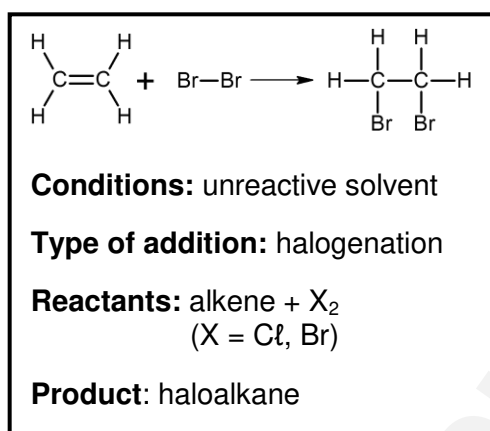


3.2 Reactions of alkenes

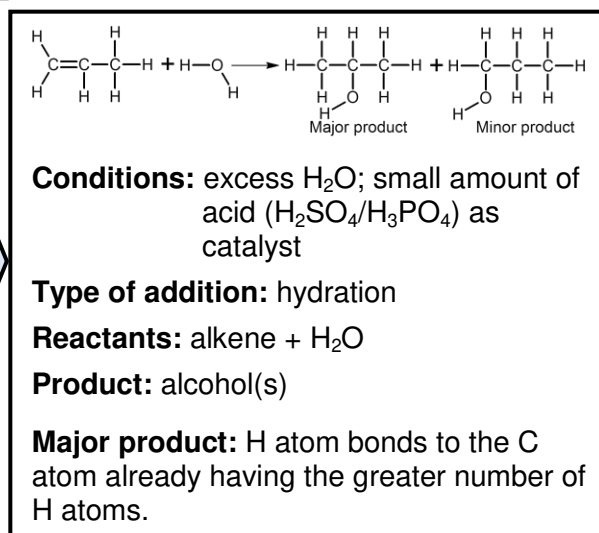
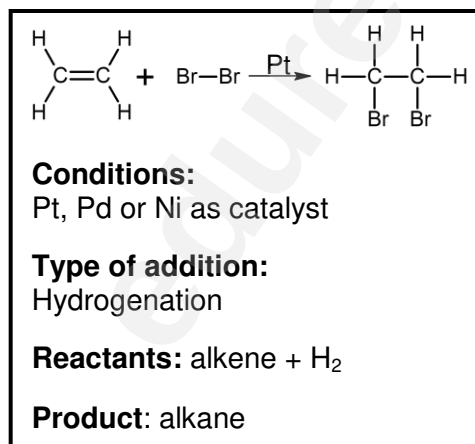
Alkenes (olefins) contain carbon-carbon double bonds and are unsaturated hydrocarbons.

Due to the presence of a double bond (electron-rich site), alkenes undergo addition reactions during which the double bond is broken and two elements are added to the molecule.

The four types of addition reactions of alkenes are summarised in the mind map below.



REACTIONS OF ALKENES

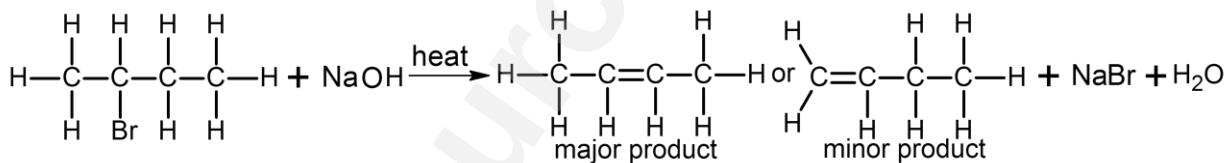


3.3 Reactions of haloalkanes

Haloalkanes have only carbon-carbon single bonds and therefore can undergo only substitution and elimination reactions. No addition reactions will take place.

The reagents used are the same for both substitution and elimination reactions of haloalkanes. In both reactions the haloalkane reacts with sodium hydroxide or potassium hydroxide. Whether a substitution or an elimination reaction takes place, depends on the reaction conditions summarized below.

Reaction conditions	
Elimination	Substitution
High temperatures	Mild/Moderate temperatures
Concentrated solution of sodium hydroxide/NaOH/potassium hydroxide/KOH	Dilute solution of sodium hydroxide/NaOH/potassium hydroxide/KOH
Pure ethanol as the solvent	More water in the solvent mixture



Conditions: concentrated strong base (NaOH/KOH/LiOH) (in ethanol) + heat

Type of elimination: dehydrohalogenation

Reactants: haloalkane + concentrated strong base **Products:** alkene + NaBr + H₂O

Major product: Compound where H atom is removed from C atom with the least number of H atoms

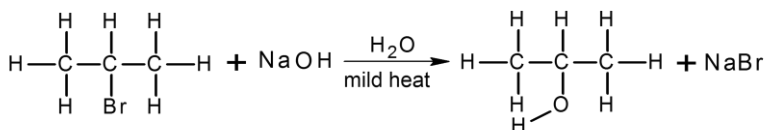
ELIMINATION

Haloalkane → alkene

REACTIONS OF HALOALKANES

SUBSTITUTION

Haloalkane → alcohol

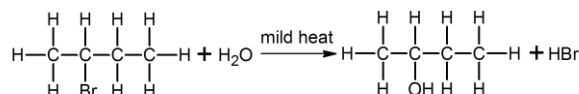


Conditions:

dilute strong base (NaOH/KOH/LiOH) + mild heat

Type of substitution: hydrolysis

Reactants: haloalkane + dilute strong base



Conditions: excess H₂O + mild heat

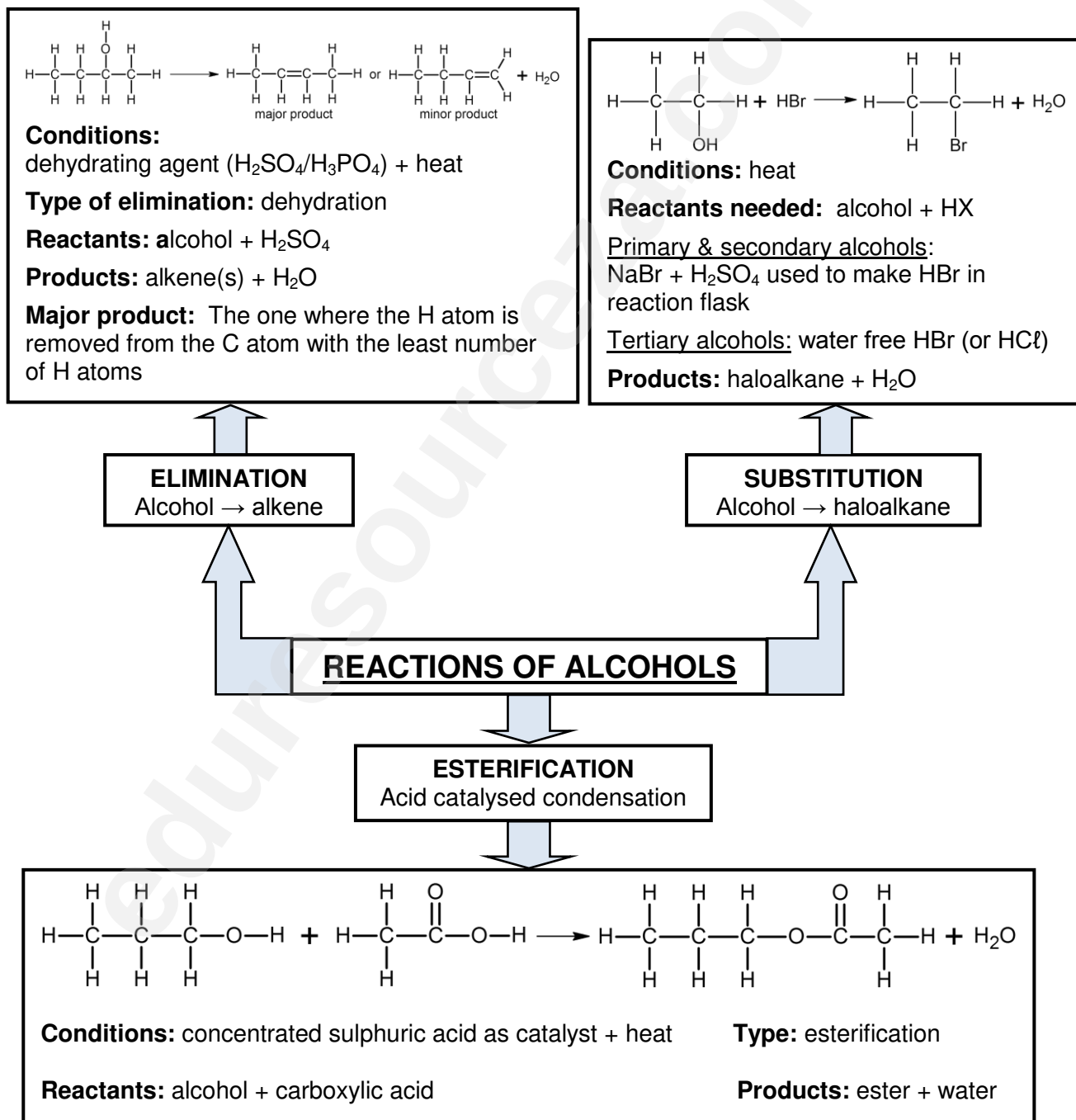
Type of substitution: hydrolysis

Reactants: haloalkane + H₂O

3.4 Reactions of alcohols

Alcohols have only carbon-carbon single bonds and therefore can undergo only substitution and elimination reactions. No addition reactions will take place.

The reactions of alcohols are summarised in the flow diagram below.



Activity 3: Organic Reactions



Answer the following questions in pairs.

QUESTION 1

Give one word or term for each of the following statements.

- 1.1 The type of addition reaction in which a hydrogen halide reacts with an alkene
- 1.2 The type of chemical reaction that takes place when an alcohol reacts with a carboxylic acid
- 1.3 The reaction type that can be used to convert hydrocarbons with high molecular masses to hydrocarbons with low molecular masses
- 1.4 The process in which large alkane molecules are broken up into smaller alkanes and alkenes
- 1.5 The type of addition reaction in which a hydrogen halide is added to an alkene
- 1.6 The type of elimination reaction during which a hydrogen halide is removed from a haloalkane
- 1.7 The type of addition reaction in which water reacts with an alkene
- 1.8 Elimination of H_2O from an alcohol
- 1.9 The reaction of alkanes and alkenes with halogens

QUESTION 2

Four options are provided as possible answers to the following questions. Each question has only ONE correct answer. Choose the answer and write only the letter (A–D) next to the question number.

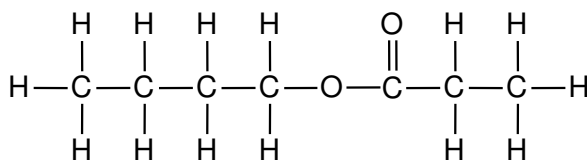
- 2.1 Which ONE of the following pairs of reactants can be used to prepare the ester ethyl butanoate in the laboratory?

A Ethanal and butan-1-ol	B Ethanoic acid and butan-1-ol
C Ethanol and butanoic acid	D Ethanal and butanoic acid
- 2.2 Which ONE of the following reaction types can be used to prepare ethene from octane?

A Addition	B Hydrogenation
C Cracking	D Substitution
- 2.3 Which ONE of the following pairs of compounds correctly represents the products formed during the COMPLETE combustion of octane?

A CO and H_2O	B CO and H_2
C CO_2 and H_2	D CO_2 and H_2O

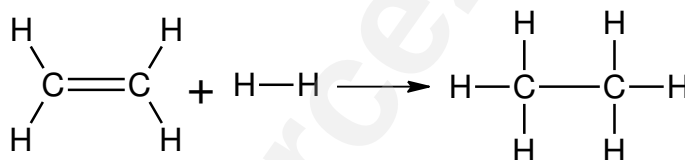
2.4 The structural formula of an ester is shown below.



Which ONE of the following pairs of compounds can be used to prepare the above ester?

- A Propanoic acid and butan-1-ol
- B Propanoic acid and butan-2-ol
- C Butanoic acid and propan-1-ol
- D Butanoic acid and propan-2-ol

2.5 Consider the reaction represented below.



The reaction is an example of ...

- | | |
|----------------|-----------------|
| A addition. | B oxidation. |
| C elimination. | D substitution. |

2.6 Which ONE of the following pairs of reactants can be used to prepare the ester ethyl methanoate in the laboratory?

- | | |
|------------------------------|------------------------------|
| A Ethane and methanoic acid | B Methanol and ethanoic acid |
| C Ethanol and methanoic acid | D Ethene and methanol |

2.7 The addition of hydrogen to an alkene is known as ...

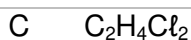
- | | |
|------------------|----------------------|
| A hydration. | B cracking. |
| C hydrogenation. | D hydrohalogenation. |

2.8 Which ONE of the following is a product formed during the hydrolysis of bromoethane?

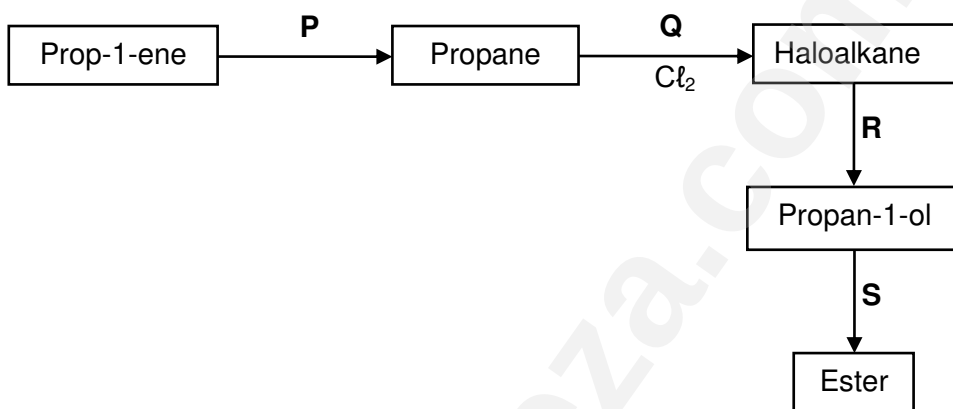
- | | |
|-----------|-----------|
| A Water | B Ethene |
| C Ethanol | D Bromine |

2.9 Which ONE of the following is the EMPIRICAL FORMULA of 1,2-dichloroethane?

- | | |
|-----------------|--------------------------|
| A CHCl | B CH_2Cl |
|-----------------|--------------------------|

**QUESTION 3**

The flow diagram below shows the preparation of an ester using prop-1-ene as a starting reagent. **P**, **Q**, **R** and **S** represent different organic reactions.



3.1 Write down the type of reaction represented by:

3.1.1 **Q**

3.1.2 **R**

3.2 For reaction **P** write down the:

3.2.1 Type of addition reaction

3.2.2 Balanced equation using structural formulae

3.3 Write down the structural formula of the haloalkane formed in reaction **Q**.

3.4 For reaction **R**, write down:

3.4.1 TWO reaction conditions

3.4.2 FORMULA of the inorganic reactant needed

3.5 In reaction **S** propan-1-ol reacts with ethanoic acid to form the ester. For this reaction write down the:

3.5.1 Name of the reaction that takes place

3.5.2 FORMULA or NAME of the catalyst needed

3.5.3 Structural formula of the ester formed

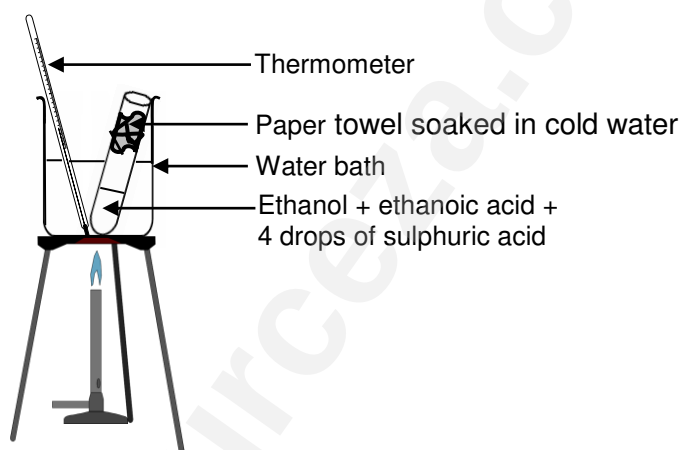
3.5.4 IUPAC name of the ester formed

3.6 The propan-1-ol formed in reaction **R** can be converted to prop-1-ene. Write down the FORMULA or NAME of the inorganic reagent needed.

QUESTION 4

A learner wants to prepare ethyl ethanoate in the school laboratory. She follows the instructions below.

- Mix 1 cm³ ethanoic acid and 1 cm³ ethanol thoroughly in a test tube.
- Slowly add 4 drops of concentrated sulphuric acid while swirling the test tube.
- Soak a paper towel in cold water and fasten it around the test tube close to its mouth with an elastic band.
- Place the test tube in a water bath and heat the water with a flame to a temperature of about 60 °C.
- Leave the test tube in the hot water bath for about 15 minutes.
- Cool the test tube by placing it in a beaker of cold water.
- Smell the vapour in the test tube after 10 minutes.

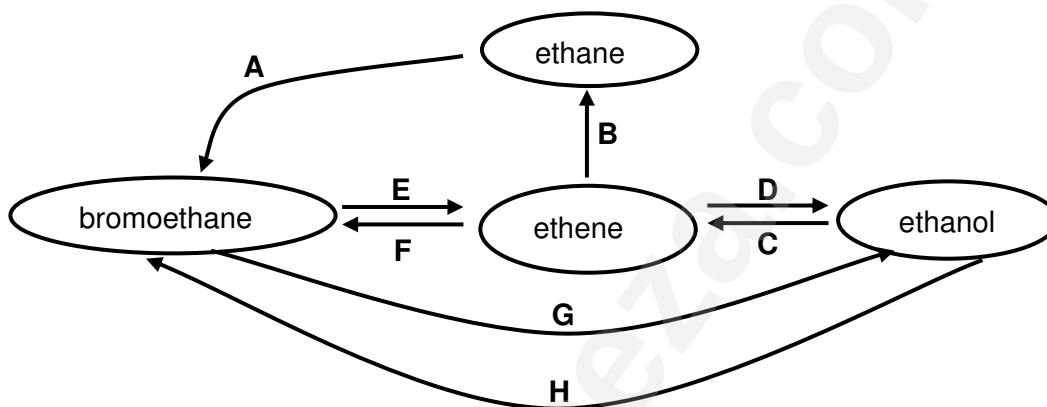


- 4.1 To which homologous series does ethanol belong?
- 4.2 Using structural formulae, write down a balanced equation for the reaction taking place in the test tube.
- 4.3 What is the function of the sulphuric acid in the above reaction?
- 4.4 Why does the method use a water bath instead of direct heating over an open flame?
- 4.5 State ONE function of the wet paper towel at the top of the test tube.
- 4.6 The learner finds it difficult to detect the smell of the ester due to the presence of sulphuric acid and unreacted ethanoic acid. A friend suggests that she must add 10 drops of a diluted sodium carbonate solution to the contents of the test tube. Briefly explain why this suggestion might be a solution to the problem.
- 4.7 Whilst several esters may be present in wine, the observed aroma is generally that of the smallest ester present in wine, namely ethyl ethanoate. State a physical property of ethyl ethanoate which is responsible for this.

QUESTION 5

Ethene is a gaseous hormone associated with the ripening of fruit. It also contributes to the ageing and distortion of plants. In industry, the artificial ripening of fruit takes place when ethene is passed over the fruit in large rooms. After a while the ripening fruit releases its own ethene.

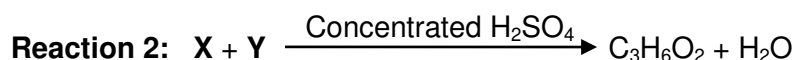
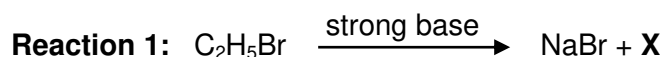
- 5.1 Write down the structural formula of ethene.
- 5.2 Why is it not advisable to place a banana that has been artificially ripened alongside a cabbage and lettuce?
- 5.3 In industry ethene is also used to synthesise a variety of organic compounds. The flow diagram below illustrates some of the many reactions ethene undergoes.



- 5.3.1 Write down the general formula for the homologous series to which ethene belongs.
- 5.3.2 Name the type of reaction represented by each of the letters **A**, **B**, **D** and **H**. Write down the letters **A**, **B**, **D** and **H** and next to each the type of reaction.
- 5.3.3 Use structural formulae to write down a balanced equation for reaction **B**.
- 5.3.4 Apart from ethene, which other reactant is needed for reaction **F**? Write down the FORMULA only.
- 5.3.5 Both reactions **E** and **G** occur in the presence of a base. Reaction **E** is an elimination reaction and reaction **G** is a substitution reaction.
- (a) How is the base in reaction **E** different from the base in reaction **G**?
- (b) Name the type of elimination reaction represented by **E**.

QUESTION 6

Consider the incomplete equations of two reactions below. **X** represents the organic product formed in **reaction 1**, which is a SUBSTITUTION REACTION. In **reaction 2**, **X** reacts with reactant **Y** as shown.



- 6.1 Consider **reaction 1**. Write down the:

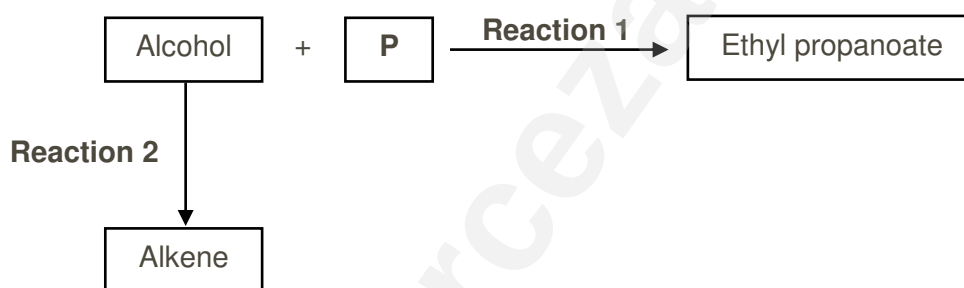
- 6.1.1 Type of substitution reaction that takes place
- 6.1.2 TWO reaction conditions
- 6.1.3 IUPAC name of compound **X**

6.2 Consider **reaction 2**. Write down the:

- 6.2.1 Type of reaction that takes place
- 6.2.2 Structural formula of compound **Y**
- 6.2.3 IUPAC name of the organic product

QUESTION 7

- 7.1 The flow diagram below shows two organic reactions. The letter **P** represents an organic compound.



Use the information in the flow diagram to answer the questions that follow.

Write down the:

- 7.1.1 Type of reaction of which **reaction 1** is an example
 - 7.1.2 STRUCTURAL FORMULA of the functional group of ethyl propanoate
 - 7.1.3 IUPAC name of compound **P**
- Reaction 2** takes place in the presence of an acid catalyst and heat. Write down the:
- 7.1.4 Type of reaction of which **reaction 2** is an example
 - 7.1.5 NAME or FORMULA of the acid catalyst
 - 7.1.6 STRUCTURAL FORMULA of the alkene

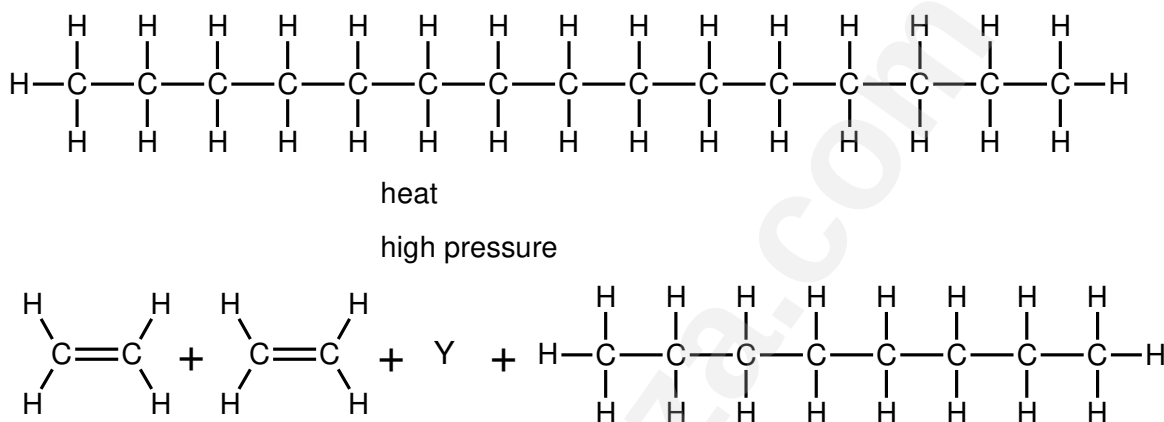
QUESTION 8

Petrol is a complex mixture of hydrocarbons such as hexane. Compounds such as 2,2,4-trimethylpentane are added to petrol to change its combustion properties.

- 8.1 Explain the term *hydrocarbon*.
- 8.2 Complete the following equation that represents the complete combustion of hexane in a car engine. (Balancing of the equation is not required.)
$$\text{C}_6\text{H}_{14} + \text{O}_2 \rightarrow \dots + \dots$$
- 8.3 Write down the structural formula for 2,2,4-trimethylpentane.
- 8.4 Petrol requires alkanes in the range from C_5 to C_{10} . Cracking is the process that is

used to convert longer chains into shorter chains.

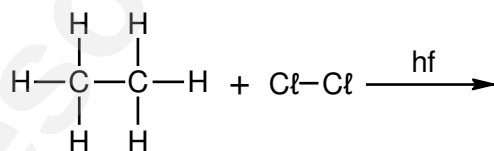
The diagram below illustrates one of the possible cracking reactions of $C_{15}H_{32}$.



Write down the STRUCTURAL FORMULA and IUPAC NAME for the hydrocarbon represented by Y.

QUESTION 9

Consider the incomplete equation for a reaction below.



Write down the:

- 9.1 Type of reaction that takes place
- 9.2 Structural formula of the product that will form in the first step of the reaction
- 9.3 Formula of the other product that will be formed QUESTION 9.2
- 9.4 IUPAC name of the compound in QUESTION 9.2

QUESTION 10

Methane reacts with bromine. Four haloalkanes can form as products during this reaction.

- 10.1 Under which conditions will this reaction take place?
- 10.2 What type of reaction takes place?
- 10.3 Write down the structural formulae and IUPAC names of the four haloalkanes that can form during this reaction.

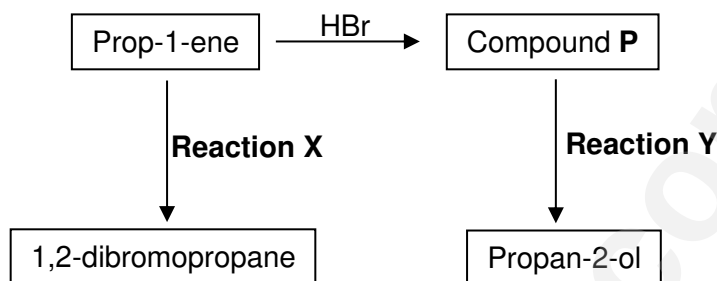
Prop-1-ene, an UNSATURATED hydrocarbon, and compound **X**, a SATURATED hydrocarbon, react with chlorine, as represented by the incomplete equations below.

Reaction II: $X + Cl_2 \rightarrow \text{2-chlorobutane} + Y$

- PHYSICAL SCIENCES: ORGANIC MOLECULES

QUESTION 12

The flow diagram below illustrates how different organic compounds can be prepared from prop-1-ene.



12.1 Reaction **X** represents the conversion of prop-1-ene to 1,2-dibromopropane.

Write down:

12.1.1 The homologous series to which 1,2-dibromopropane belongs

12.1.2 The balanced equation for reaction **X**, using structural formulae

12.1.3 The type of reaction represented by **X**

Choose from ELIMINATION, ADDITION or SUBSTITUTION.

12.2 Write down the structural formula of compound **P**, the major product formed when prop-1-ene reacts with HBr.

12.3 Compound **P** is converted to propan-2-ol during reaction **Y** in the presence of a strong base.

12.3.1 Write down TWO reaction conditions needed for reaction **Y** to take place.

12.3.2 Classify propan-2-ol as a PRIMARY, SECONDARY or TERTIARY alcohol.

12.3.3 Write down the type of substitution reaction of which reaction **Y** is an example.

12.4 Propan-2-ol can be converted to prop-1-ene.

12.4.1 Write down the NAME or FORMULA of a reactant that can be used for this reaction.

12.4.2 What type of reaction takes place? Choose from HYDRATION, DEHYDRATION or HYDROLYSIS.



3. UNIT 4: Plastics and polymers

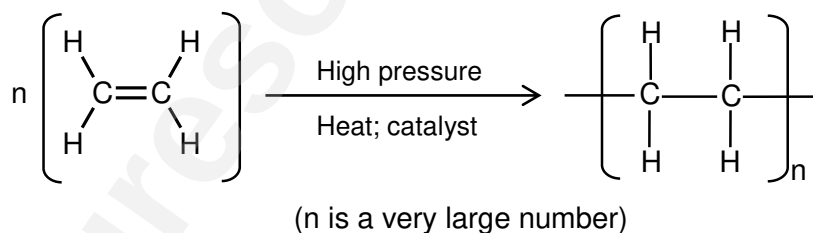
Polymers are long chain giant organic molecules assembled from many smaller molecules called **monomers**. Polymers consist of many repeating monomer units in long chains. A polymer is analogous to a necklace made from many small beads (monomers).



Depending on the number of monomers joined together, a polymer can become very large. Giant covalent structures are called **macromolecules**

4.1 Addition polymerization

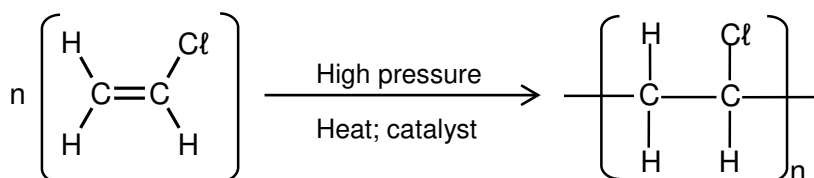
Many monomers are alkenes which react by addition to their unsaturated double bonds. The formation of polyethene (polythene) from ethene is illustrated below:



In the complete polymer, all of the double bonds have been turned into single bonds. **No atoms have been lost and you can see that the monomers have just been joined in the process of addition.** A simple representation is -[A-A-A-A-A]-.

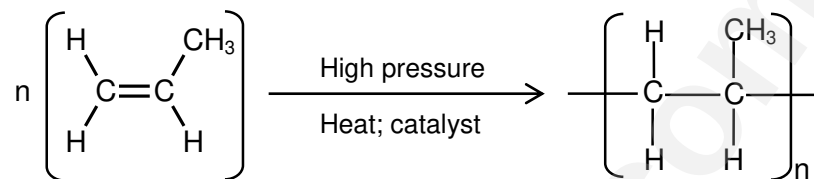
Other types of addition polymers

PVC (polyvinyl chloride) which is found in plastic wrap, simulated leather, water pipes, and garden hoses, is formed from chloroethene ($\text{H}_2\text{C}=\text{CHCl}$). The reaction is shown below:



Every other carbon must have a chlorine atom attached. The recycling number of PVC is 3.

Polypropylene (PP): The reaction to make polypropylene from propene ($\text{H}_2\text{C}=\text{CHCH}_3$) is illustrated below:



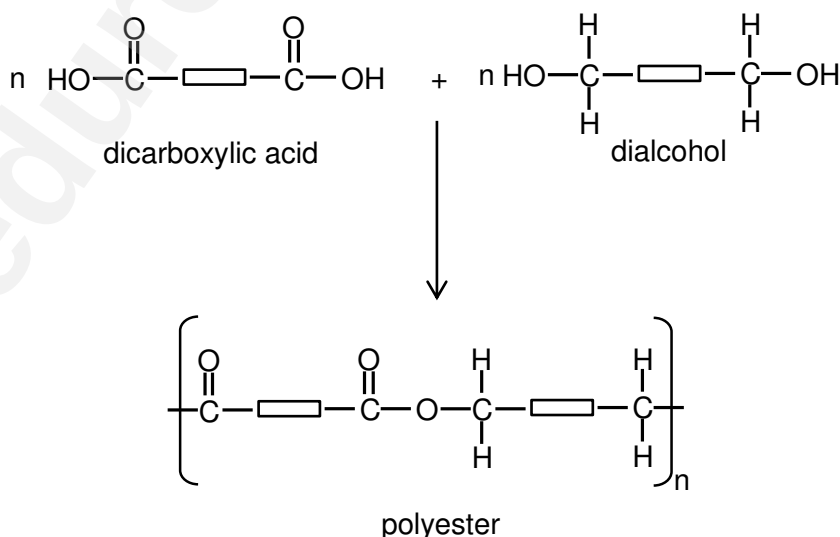
The polymer bonds are always through the carbons of the double bond. Carbon 3 already has saturated bonds and cannot participate in any new bonds. A methyl group is on every other carbon. PP is used to make tupperware, yogurt tubs, and plastic caps of soda bottles and has the recycling number 5.

4.2 Condensation polymerization

In condensation polymerisation, **a small molecule is formed as a by-product each time a bond is formed between two monomers**. This small molecule is often water. Nylon and polyester are examples of condensation polymers.

If an alcohol reacts with a carboxylic acid, an ester is formed. The link between the $-\text{OH}$ group and the $-\text{COOH}$ group with the loss of H_2O is called an ester link.

When a molecule with two carboxyl groups ($-\text{COOH}$), one at each end, reacts with a molecule with two hydroxyl groups ($-\text{OH}$), many ester links are possible. The result is a polyester.

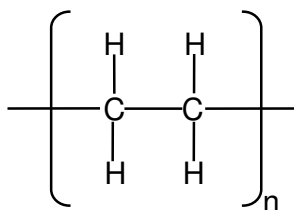


Activity 4: Polymerization reactions



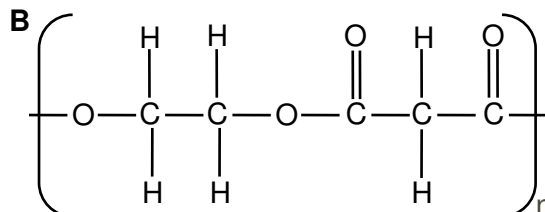
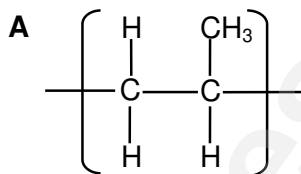
Answer the following questions in pairs.

1. The condensed formula of a polymer is shown below.



- 1.1 Define the term *monomer*.
- 1.2 Write down the:
- 1.2.1 STRUCTURAL FORMULA of the monomer that is used to prepare the above polymer
- 1.2.2 Type of polymerisation reaction (ADDITION or CONDENSATION) that is used to prepare this polymer

1. Consider the two polymers below.



- 2.1 Write down the structural formulae of the monomer(s) in:
- 2.2.1 **A**
- 2.2.2 **B**
- 2.2 Classify the following polymers as ADDITION or CONDENSATION polymers.
- 2.3 During the formation of which polymer (**A** or **B**) is a small molecule split out?

4. Summative Task



Answer the questions below in preparation for the post-test.

QUESTION 1: Multiple choice questions

- 1.1 Which ONE of the following compounds is an aldehyde?
- A CH_3COCH_3
 - B $\text{CH}_3\text{CH}_2\text{CHO}$
 - C $\text{CH}_3\text{CH}_2\text{COOH}$
 - D $\text{CH}_3\text{CH}_2\text{CH}_2\text{OH}$
- (2)
- 1.2 Which ONE of the following compounds will react with sodium hydroxide (NaOH) in a neutralisation reaction?
- A CH_3CHO
 - B CH_3COOH
 - C CH_3COCH_3
 - D $\text{CH}_3\text{CH}_2\text{OH}$
- (2)
- 1.3 Which ONE of the following pairs of compounds are FUNCTIONAL isomers?
- A Methanol and methanal
 - B Butane and 2-methylpropane
 - C Propan-1-ol and propan-2-ol
 - D Propanoic acid and methyl ethanoate
- (2)

QUESTION 2

- 2.1 Define the term boiling point. (2)
- 2.2 What is the relationship between strength of intermolecular forces and boiling point? (1)

The relationship between strength of intermolecular forces and boiling point is investigated using four organic compounds from different homologous series. The compounds and their boiling points are given in the table below.

	Compound	Boiling point ($^{\circ}\text{C}$)
A	Propane	-42
B	Propan-2-ol	56
C	Propan-1-one	97
D	Propanoic acid	141

2.3 Refer to the TYPE and the STRENGTH of intermolecular forces to explain the difference in boiling points between:

2.3.1 Compounds **A** and **B** (3)

2.3.2 Compounds **C** and **D** (3)

2.4 Is compound B a GAS or a LIQUID at room temperature? (1)

[10]

Question 3

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

A	$ \begin{array}{c} \text{H} \quad \text{H} \quad \text{O} \\ \quad \quad \\ \text{H}-\text{C}-\text{C}-\text{C}-\text{O}-\text{H} \\ \quad \\ \text{H} \quad \text{H} \end{array} $	B	$ \begin{array}{ccccccc} & & & & \text{H} & & \\ & & & & & & \\ & & & & \text{H}-\text{C}-\text{H} & & \\ & & & & & & \\ \text{H} & \text{H} & \text{H} & \text{H} & & \text{H} & \text{H} \\ & & & & & & \\ \text{H}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{H} \\ & & & \text{Cl} & & & \\ \text{H} & & \text{H} & & \text{H} & \text{H} & \text{H} \\ & & & & & & \\ & & \text{H}-\text{C}-\text{H} & & & & \\ & & & & & & \\ & & \text{H} & & & & \end{array} $
C	C_4H_8	D	$\text{CH}_3\text{CH}_2\text{COCH}_3$
E	$\text{CH}_3\text{CH}(\text{CH}_3)\text{CH}_2\text{OH}$	F	$ \begin{array}{ccccccc} \text{H} & \text{H} & \text{H} & \text{H} & \text{H} & \text{H} & \\ & & & & & & \\ \text{H}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{H} \\ & & & & & & \\ \text{H} & \text{H} & \text{H} & \text{H} & \text{H} & \text{H} & \end{array} $

Use the information in the table (where applicable) to answer the questions that follow.

3.1 Write down the LETTER that represents a compound that:

(A compound may be used more than once.)

3.1.1 Is a haloalkane (1)

3.1.2 Has a hydroxyl group as functional group (1)

3.1.3 Belongs to the same homologous series as ethanoic acid (1)

3.2 Write down the:

3.2.1 IUPAC name of compound **B** (3)

3.2.2 IUPAC name of compound **E** (2)

3.2.3 Structural formula of the functional group of compound **D** (1)

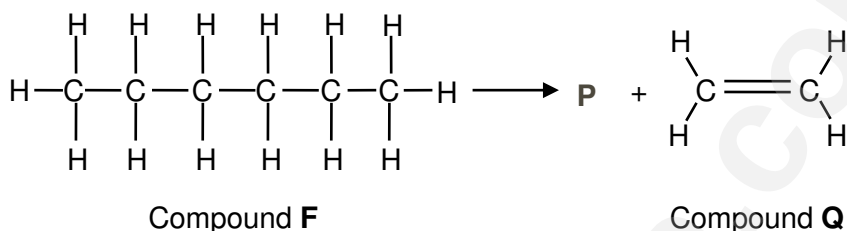
3.3 Compound **C** has CHAIN and POSITIONAL isomers.

3.3.1 Define the term positional isomer. (2)

3.3.2 Write down the IUPAC name of each of the TWO positional isomers of compound **C**. (4)

3.3.3 Write down the structural formula of a chain isomer of compound **C**. (2)

3.4 Compound **F** reacts at high pressure and high temperature to form compounds **P** and **Q** as given below.



Write down the:

3.4.1 Type of reaction that takes place (1)

3.4.2 IUPAC name of compound **Q** (1)

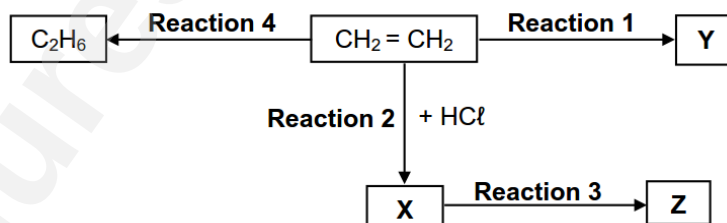
3.4.3 Molecular formula of compound **P** (1)

Compound **Q** is the monomer of a polymer used to make plastic bags.

3.4.4 Write down the NAME and CONDENSED FORMULA of this polymer. (3)
[23]

QUESTION 4

The flow diagram below shows different organic reactions using $\text{CH}_2 = \text{CH}_2$ as the starting reactant. **X**, **Y** and **Z** represent different organic compounds.



4.1 During Reaction 1, $\text{CH}_2 = \text{CH}_2$ undergoes polymerisation to form compound **Y**. For this reaction, write down the:

4.1.1 Type of polymerization (1)

4.1.2 NAME of compound **Y** (1)

4.2 For Reaction 2, write down the:

4.2.1 IUPAC name of compound **X** (2)

4.2.2 Type of addition reaction of which this is an example (1)

- 4.3 During Reaction **3**, compound **X** reacts with excess hot water.
Write down the:
- 4.3.1 STRUCTURAL FORMULA of compound **Z** (2)
- 4.3.2 NAME or FORMULA of the INORGANIC product (1)
- 4.4 Reaction **4** is an addition reaction.
- 4.4.1 Is C_2H_6 a SATURATED or an UNSATURATED compound? Give a reason for the answer. (2)
- 4.4.2 Write down the NAME or FORMULA of the INORGANIC reactant needed for this reaction. (1)
- 4.4.3 Using molecular formulae, write down a balanced equation for the complete combustion of C_2H_6 . (3)
- [14]**

GRAND TOTAL: 53

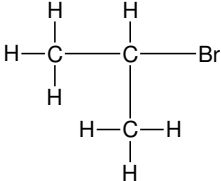
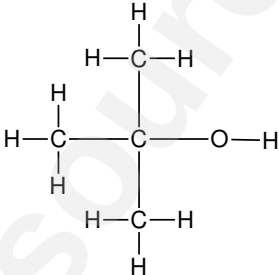
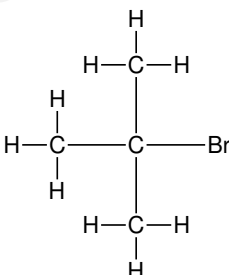
5. Glossary



Term	Explanation
<i>Addition reaction</i>	A reaction in which a double bond in the starting material is broken and elements are added to it.
<i>Addition polymer</i>	A polymer formed when monomers (usually containing a double bond) combine through an addition reaction
<i>Addition polymerisation:</i>	A reaction in which small molecules join to form very large molecules by adding on double bonds
<i>Alcohol</i>	An organic compound in which H atoms in an alkane have been substituted with hydroxyl groups (-OH groups). General formula: $C_nH_{2n+1}OH$
<i>Aldehydes</i>	Organic compounds having the general structure RCHO where R = H or alkyl. General formula: RCHO (R = alkyl group)
<i>Alkane</i>	An organic compound containing only C-H and C-C single bonds. General formula: C_nH_{2n+2}
<i>Alkene</i>	A compound of carbon and hydrogen that contains a carbon-carbon double bond. General formula: C_nH_{2n}
<i>Alkyl group</i>	A group formed by removing one H atom from an alkane.
<i>Alkyne</i>	A compound of carbon and hydrogen that contains a carbon-carbon triple bond.
<i>Boiling point</i>	The temperature at which the vapour pressure of a liquid equals atmospheric pressure.
<i>Carbonyl group</i>	Functional group of ketones ($>C=O$)
<i>Carboxyl group</i>	Functional group of carboxylic acids (-COOH)
<i>Carboxylic acid</i>	An organic compound containing a carboxyl group (-COOH group). General formula: $C_nH_{2n+1}COOH$ (or RCOOH)
<i>Chain isomers</i>	Compounds with the same molecular formula, but different types of chains.
<i>Condensation polymer</i>	A polymer formed by two monomers with different functional groups that are linked together in a condensation reaction in which a small molecule, usually water, is lost
<i>Condensation polymerisation</i>	Molecules of two monomers with different functional groups undergo condensation reactions with the loss of small molecules, usually water
<i>Condensed structural</i>	A formula that shows the way in which atoms are bonded

Term	Explanation
<i>formula</i>	together in the molecule, but DOES NOT SHOW ALL bond lines.
<i>Cracking</i>	The chemical process in which longer chain hydrocarbon molecules are broken down to shorter more useful molecules.
<i>Dehydration</i>	Elimination of water from a compound usually such as an alcohol.
<i>Dehydrohalogenation</i>	The elimination of hydrogen and a halogen from a haloalkane.
<i>Dipole-dipole force</i>	Intermolecular forces found between polar molecules i.e. molecules in which there is an uneven distribution of charge so that the molecule has a positive and a negative side.
<i>Elimination reaction</i>	A reaction in which elements of the starting material are “lost” and a double bond is formed.
<i>Esterification</i>	The preparation of an ester from the reaction of a carboxylic acid with an alcohol.
<i>Functional group</i>	A bond or an atom or a group of atoms that determine(s) the physical and chemical properties of a group of organic compounds.
<i>Functional isomers</i>	Compounds with the same molecular formula, but different functional groups.
<i>Haloalkane</i> (Alkyl halide)	An organic compound in which one or more H atoms in an alkane have been replaced with halogen atoms. General formula: $C_nH_{2n+1}X$ (X = F, Cl, Br or I)
<i>Halogenation</i>	The reaction of a halogen (Br_2 , Cl_2) with a compound.
<i>Homologous series</i>	A series of organic compounds that can be described by the same general formula. OR A series of organic compounds in which one member differs from the next with a CH_2 group.
<i>Hydration</i>	The addition of water to a compound.
<i>Hydrocarbon</i>	Organic compounds that consist of hydrogen and carbon only.
<i>Hydrogenation</i>	The addition of hydrogen to an alkene
<i>Hydrogen bond</i>	A strong intermolecular force found between molecules in which an H atom is covalently bonded to wither an N, O or F atom.
<i>Hydrohalogenation</i>	The addition of a hydrogen halide to an alkene
<i>Hydrolysis</i>	The reaction of a compound with water
<i>Intermolecular force</i>	Forces between molecules that determine physical properties of compounds.
<i>IUPAC name</i>	A chemical nomenclature (set of rules) created and developed by the International Union of Pure and Applied Chemistry (IUPAC) to generate systematic names for chemical compounds.
<i>London force</i>	A weak intermolecular force between non-polar molecules.

Term	Explanation
(dispersion force)	
Macromolecule	A molecule that consists of a large number of atoms
Melting point	The temperature at which the solid and liquid phases of a substance are at equilibrium.
Molecular formula	A chemical formula that indicates the type of atoms and the correct number of each in a molecule, e.g. CH ₄ .
Monomer	Small organic molecules that can be covalently bonded to each other in a repeating pattern
Organic chemistry	Chemistry of carbon compounds.
Polymer	A large molecule composed of smaller monomer units covalently bonded to each other in a repeating pattern
Polymerisation	A chemical reaction in which monomer molecules join to form a polymer
Positional isomer	Compounds with the same molecular formula, but different positions of the side chain, substituents or functional groups on the parent chain.
Primary alcohol	One C atom is bonded to the C atom bonded to hydroxyl group. Example: $ \begin{array}{c} \text{H} \quad \text{H} \\ \quad \\ \text{H}-\text{C}-\text{C}-\text{O}-\text{H} \\ \quad \\ \text{H} \quad \text{H} \end{array} $
Primary haloalkane	One C atom is bonded to the C atom bonded to the halogen. Example: $ \begin{array}{c} \text{H} \quad \text{H} \\ \quad \\ \text{H}-\text{C}-\text{C}-\text{Br} \\ \quad \\ \text{H} \quad \text{H} \end{array} $
Saturated compounds	Compounds in which there are no multiple bonds between C atoms in their hydrocarbon chains. OR Compounds with only single bonds between C atoms in their hydrocarbon chains.
Secondary alcohol	Two C atoms bonded to the C atom that is bonded to hydroxyl group. Example: $ \begin{array}{c} \text{H} \quad \text{H} \\ \quad \\ \text{H}-\text{C}-\text{C}-\text{O}-\text{H} \\ \quad \\ \text{H} \quad \text{H}-\text{C}-\text{H} \\ \quad \\ \quad \text{H} \end{array} $
Secondary haloalkane	Two C atoms bonded to the C atom bonded to the halogen. Example:

Term	Explanation
	
<i>Structural formula</i>	A structural formula of a compound shows which atoms are attached to which within the molecule. Atoms are represented by their chemical symbols and lines are used to represent ALL the bonds that hold the atoms together.
<i>Structural isomer</i>	Organic molecules with the same molecular formula, but different structural formulae.
<i>Substituent (branch)</i>	A group or branch attached to the longest continuous chain of C atoms in an organic compound.
<i>Substitution reaction</i>	A reaction in which an atom or a group of atoms in a molecule is replaced by another atom or group of atoms.
<i>Tertiary alcohol</i>	Three C atoms bonded to carbon that is bonded to hydroxyl group. Example: 
<i>Tertiary haloalkane</i>	Three C atoms bonded to the C atom bonded to the halogen. Example: 
<i>Unsaturated compounds</i>	Compounds in which there are multiple bonds (double or triple bonds) between C atoms in their hydrocarbon chains.
<i>Van der Waals forces</i>	A combined name used for the different types of intermolecular forces.
<i>Vapour pressure</i>	The pressure exerted by a vapour at equilibrium with its liquid in a closed system.

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