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THEORY & WORKBOOK

GRADE 12

PHYSICAL SCIENCES

ORGANIC CHEMISTRY

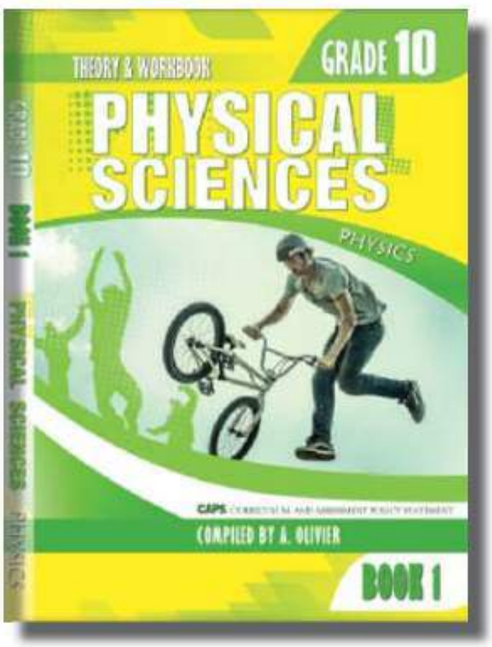


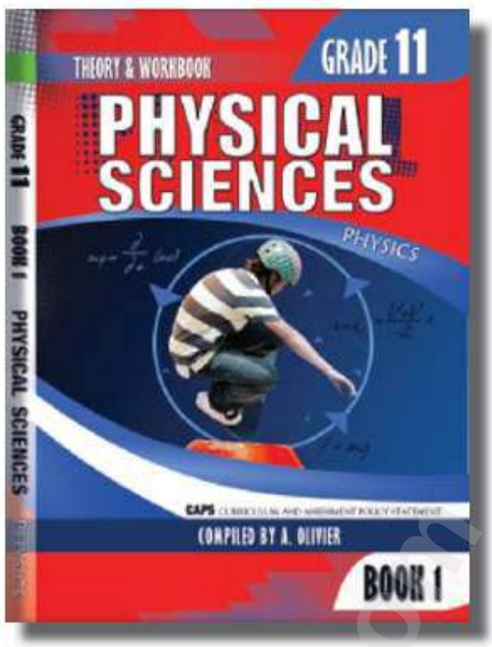
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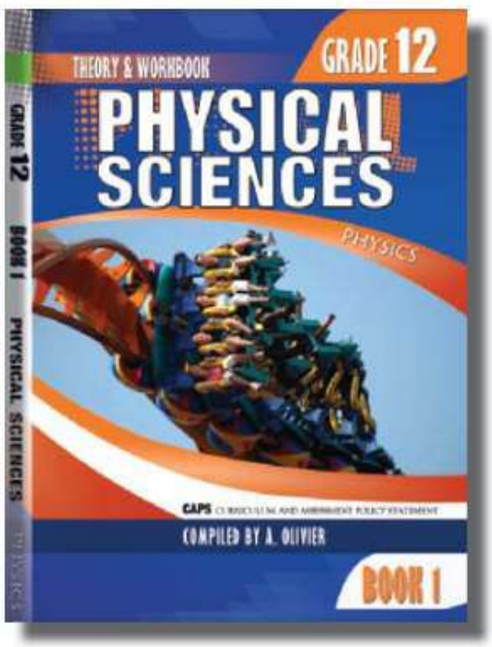
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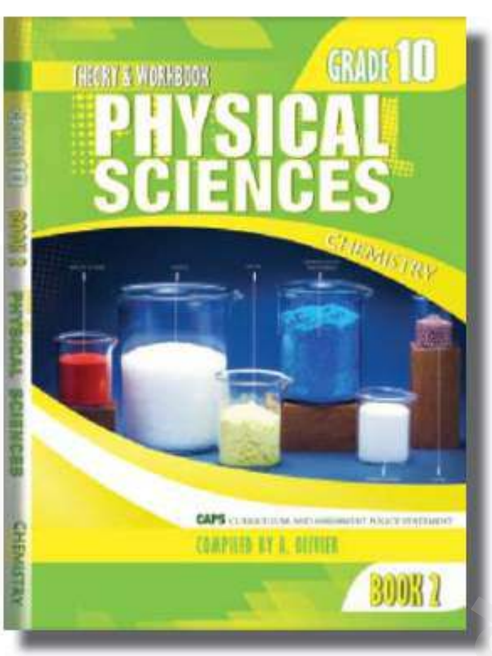
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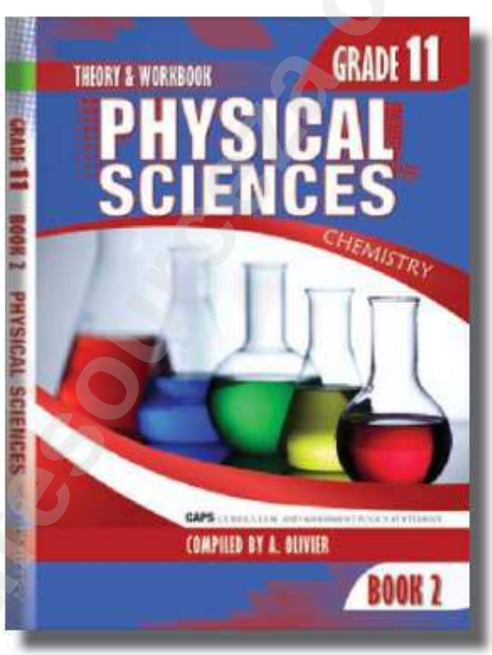
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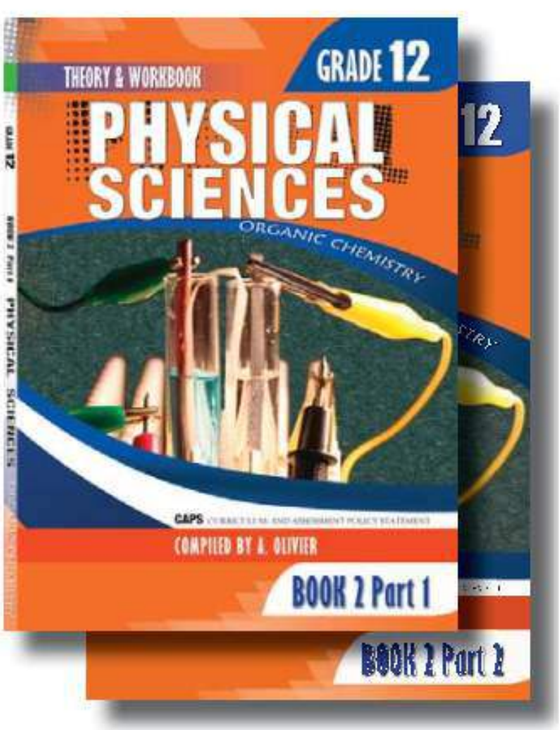












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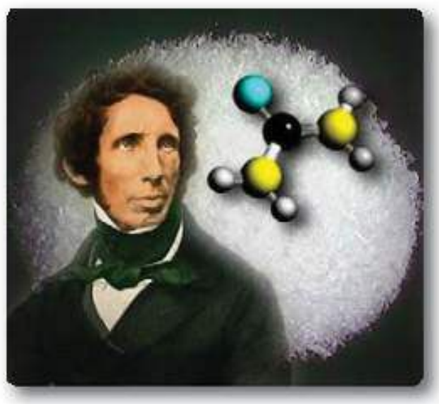
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Chapter 1 ORGANIC MOLECULES

ORGANIC MOLECULAR STRUCTURES

WHAT IS ORGANIC CHEMISTRY?

The term organic chemistry was initially used to refer to the chemistry of compounds of living material, i.e. compounds of plant or animal origin. Earlier it was believed that such compounds, which originated from living organisms, had a "life force" of their own and couldn't be synthesised in a laboratory. However, in 1828 after Friedrich Wöhler succeeded in synthesising the first organic molecule, urea (a by-product formed in the kidneys), from the inorganic compounds silver cyanide (AgCN) and ammonium chloride ($NH_4C\ell$), organic chemistry evolved into the biggest branch of chemistry. About thirteen years later, another chemist named Bertholet, synthesised a number of organic compounds by using carbon monoxide (CO) (a known inorganic compound) as raw material. There was no magic "life force" to these compounds and henceforth **organic chemistry** is referred to the **chemistry of carbon compounds**, which uses carbon (C) as the base source.



Friedrich Wöhler (1800-1882) synthesised urea from two inorganic substances, silver cyanide and ammonium chloride. He could be seen as the father of organic chemistry

Organic chemistry is the chemistry of carbon compounds.

Carbon dioxide (CO_2), Carbon monoxide (CO), carbonates (CO_3^{2-}) and cyanides (CN^-) are regarded as inorganic, despite the fact that they contain carbon (C).

PROPERTIES OF ORGANIC MOLECULES

Since Wöhler's synthesis of urea, millions of organic molecules have been synthesised and thousands more are added to this number each year. More than 90% of all compounds on earth are organic by nature. The question is why are there so many organic compounds? The answer lies in the unique bonding properties of carbon.

1																	18
H	2											13	14	15	16	17	He
Li	Be											B	C	N	O	F	Ne
Na	Mg	3	4	5	6	7	8	9	10	11	12	Al	Si	P	S	Cℓ	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	As	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Te	Sb	Te	I	Xe
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	Ac															

The position of carbon in the Periodic Table. Other elements usually found in organic compounds are also indicated.

The following unique bonding properties of carbon are mainly responsible for the existence of so many organic compounds:

- ***Carbon (C) has four valence electrons and is able to form four covalent bonds to obtain a stable octet structure.***

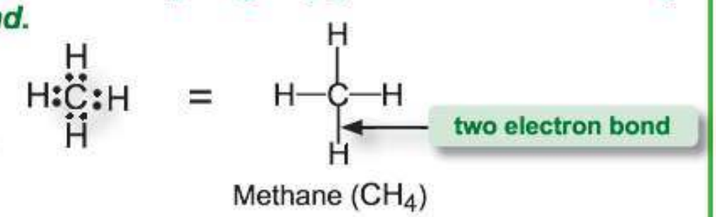
Carbon:
- has an atomic number of 6
- is a non-metal in group 14 (IV A) of the Periodic Table
- has the electron configuration: $1s^2\ 2s^2 2p^2$
- has a valency of four (has four electrons available to form four covalent bonds)



carbon has four valence electrons

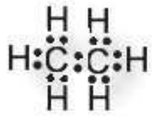
- ***All organic compounds contain carbon (C) and most of them contain hydrogen (H) as well. Carbon always forms four covalent bonds and hydrogen one covalent bond.***

With carbon in group 14 (IV A) of the Periodic Table, it has four valence electrons available for bonding, whereas hydrogen has one. A methane molecule consists of four single covalent bonds, each formed out of one electron from a H-atom and one electron from a C-atom.



Methane (CH_4)

- ***Carbon can bond covalently with other C-atoms to form single, double and triple bonds.***
  - Covalent bonds between C-atoms are relatively strong.
  - The ability of carbon to form compounds with itself is known as catenation.
  - If a compound contains two or more C-atoms, the type of bond is determined by the number of atoms surrounding the C-atoms.



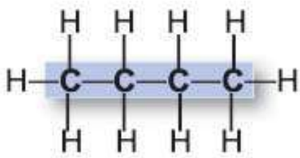


  - A C-atom surrounded by four atoms forms four single covalent bonds. In ethane (C_2H_6) each C-atom is bonded to three H-atoms and one C-atom. All bonds are single.
  - A C-atom surrounded by three atoms forms one double and two single covalent bonds. In ethene (C_2H_4) each carbon is surrounded by three atoms (two H-atoms and one C-atom); each C-atom thus forms a single bond with each H-atom and a double bond with another C-atom.
  - A C-atom surrounded by two atoms usually forms a triple covalent bond. In ethyne (C_2H_2) each carbon is surrounded by two atoms (one hydrogen and one C-atom), thus each C-atom forms a single bond with one H-atom and a triple bond with the other C-atom.

- ***C-atoms are able to bond to each other to form chains, branched chains and ring structures.***

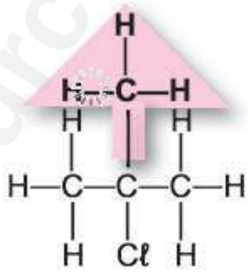
Four C-atoms could for example bond in a straight chain (row) to form butane, or a branched structure like methyl propane, or a ring structure like cyclobutane.

Chain structure



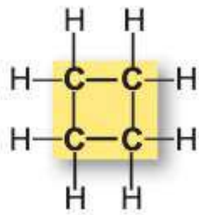
butane
C_4H_{10}

Branched Chain Structure



methyl propane
C_4H_{10}

Cyclic Structure



cyclobutane
C_4H_{10}

- ***C-atoms could also form covalent bonds with other atoms (not carbon or hydrogen).***

Any atom which is not carbon or hydrogen is known as a **heteroatom**.

The most common heteroatoms are nitrogen (N), oxygen (O), sulphur (S) and the halogens F, Cℓ, Br , I.

- Each heteroatom forms a particular number of bonds, which is determined by its position in the Periodic Table.
- In general heteroatoms also have unbounded lone pairs which satisfies the octet rule, thus each atom is surrounded by eight electrons (octet rule)

Nitrogen (N) forms thus three covalent bonds and has one lone pair, while oxygen (O) forms two bonds, with two one pairs. The halogens (F, Cℓ, Br , I) form one bond with three lone pair electrons.

The general bonding patterns for atoms in organic compounds are summarised below. With hydrogen as the exception, the other elements follow the following rule for covalent bonding:

number of bonds + **number of lone pairs** = **4**

Bonding Patterns for Atoms in Organic Compounds

	–H	–C–	–N–	–O–	–X:	X = F, Cℓ, Br, I
			Lone pair electrons			
	hydrogen	carbon	nitrogen	oxygen	halogen	
Number of bonds →	1	4	3	2	1	
Number of lone pair electrons →	0	0	1	2	3	

REPRESENTATION OF ORGANIC MOLECULES

Organic molecules are molecules that contain C-atoms. **Different formulae** are used to represent organic molecules.

1. General formula

The **general formula** describes a homologous series of organic compounds, i.e. a formula for a group of organic compounds with similar bonds.

- For example: the general formula for the homologous series of alkanes is C_nH_{2n+2}.

2. Molecular formula

A **molecular formula** is a chemical formula which indicates the type of atoms and the correct number of each in a molecule. This formula reveals no information about the type and nature of bonding between the atoms;

- For example: the molecular formula of butane is C_4H_{10}.

3. Condensed structural formula

A **condensed structural formula** shows all atoms in the molecule, but omitting some or all indication of the bonds. Generally carbon-carbon single bonds are not shown.

Sometimes the single carbon-carbon bonds are shown.

- For example, the condensed structural formula of butane is $CH_3CH_2CH_2CH_3$ or $CH_3\text{-}CH_2\text{-}CH_2\text{-}CH_3$

When branched organic molecules are present it's indicated with the branched groups in brackets.

- For example, the condensed structural formula for 2-methyl pentane is $CH_3(CH_3)CHCH_2CH_2CH_3$

If double bonds and triple bonds are present, it is indicated in the condensed structural formula.

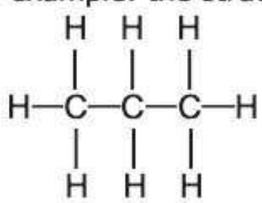
- For example, the condensed structural formula for propane is $CH_2{=}CHCH_2$ and for propanoic acid it is $CH_3CH_2\overset{\overset{O}{\|}}{C}OH$

4. Structural formula

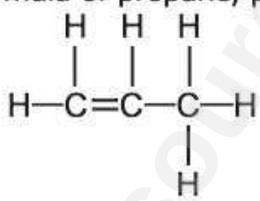
The **structural formula** of a compound indicates which atoms are attached to which in the molecule. Atoms are represented by their chemical symbols and lines are used to show ALL bonds that hold atoms together in the molecule.

A single line represents a shared electron pair (single covalent bond). Double and triple lines represent double and triple bonds respectively. Keep in mind that a C-atom always forms four bonds.

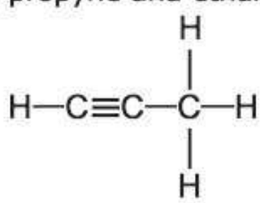
- For example: the structural formula of propane, propene, propyne and ethanoic acid is as follows.



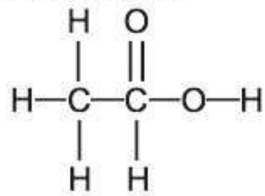
Propane



Propene



Propyne



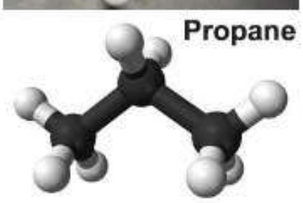
Ethanoic acid

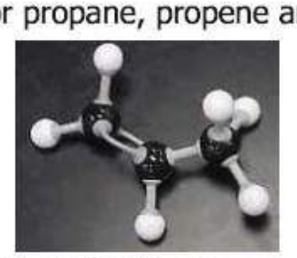
Organic molecules are also represented by three dimensional (3D) **molecular models** of the microscopic structure. Examples of such models are the **ball-and-stick model** and the **space-filling models**.

- The **ball-and-stick model** uses balls as atoms of different colours (as atoms) representing the different elements, which are connected by sticks. With the ball-and-stick model the bonding orientation can be observed.
  - For example, the **ball-and-stick models** for propane, propene and propyne are.

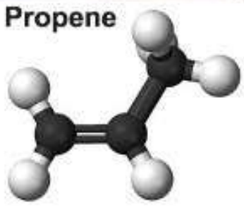


or **Propane**



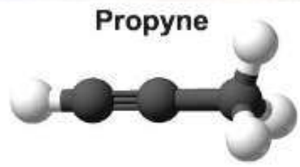


or **Propene**

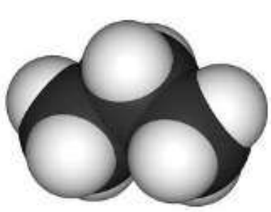




or **Propyne**



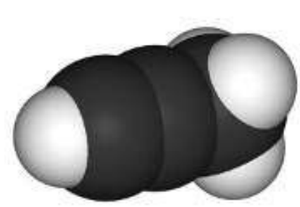
- The space filling model consists of bigger balls of different colours (as atoms) with openings and pins, which are connected and fit puzzle to give a realistic three dimensional view of the molecule.
  - For example, the space-filling models for propane, propene and propyne are.



Propane



Propene



Propyne

STRUCTURE OF ORGANIC MOLECULES

■ Variety of organic compounds

There exist more than 10 million organic compounds of which each has its own name, characteristic physical properties, such as melting and boiling points, as well as its characteristic chemical properties. It is almost impossible to study each of these compounds on its own. Chemists have however over time found that all the millions of organic compounds can be classified in a few families according to its structural properties. Compounds, belonging to a certain family show similarities in chemical behaviour. Instead of 10 million compounds with random behaviour (reactivity), the study could be narrowed to a few families.

■ Functional group

Much like the Periodic Table, where elements are divided into groups or 'families' according to their respective properties, organic compounds can be divided into separate groups according to their physical and chemical properties, each with their respective series of reactions. The structural properties which enable the classification of compounds according to their behaviour are known as **functional groups.**

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

A functional group will undergo the same type of chemical reaction, irrespective of the size of the molecule it is part of.

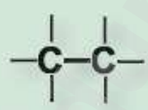
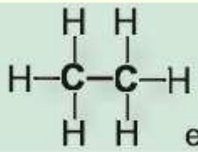
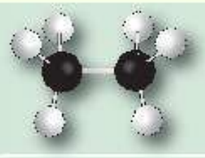
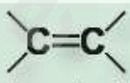
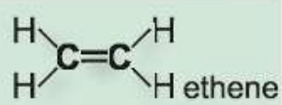
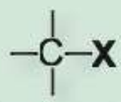
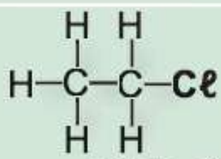
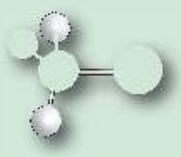
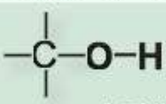
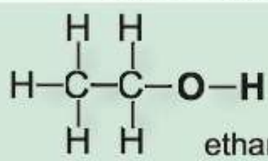
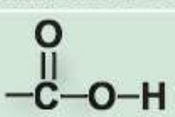
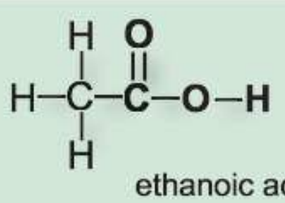
■ Homologous series

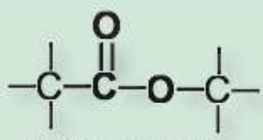
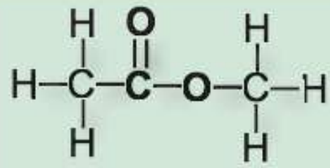
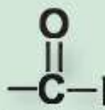
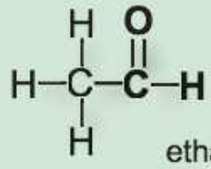
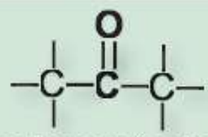
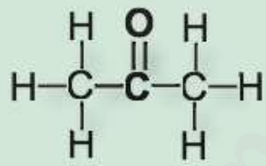
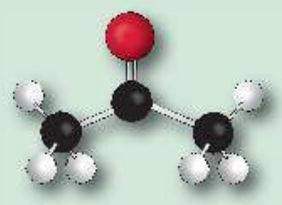
A family of organic compounds are known as a **homologous series**. Compounds of the same homologous series have the same functional group and can be described by the same general formula. Alkanes for example, could be represented by the general formula C_nH_{2n+2}. The alkane with 50 carbons would have the chemical formula of $C_{50}H_{102}$

A homologous series are a series of organic compounds that can be described by the same general formula OR in which one member differs from the next with a CH_2- group.

In a homologous series, the molecules have the same functional group, but the length of the carbon chain differs. The simplest homologous series are the alkanes. All the members of the alkanes consist of carbon and H-atoms. The C-atoms are bound with single covalent bonds to form a chain which could be straight or branched. The first member of the alkanes is methane which consists of one C-atom and four H-atoms. The second member is ethane, with two carbons and six H-atoms. The functional group of the homologous series is the single bonds between the C-atoms.

The following table shows the functional group which is applicable to this course. If one studies and understands the chemistry of the functional groups, the knowledge could be applied to numerous compounds in each group.

Homologous series and gen. formula	Functional group	Example Structural formula and name	Ball and stick model	Name ends with
Alkanes C_nH_{2n+2}	 only C-C and C-H single bonds	 ethane		-ane
Alkenes C_nH_{2n}	 carbon-carbon double bonds	 ethene		-ene
Alkynes C_nH_{2n-2}	 carbon-carbon triple bonds	 ethyne		-yne
Haloalkanes (alkyl halides) C_nH_{2n+1} + **X**	 halogen atom bound to a saturated C-atom (**X** = F, Cℓ, Br or I)	 chloro-ethane		
Alcohols C_nH_{2n+1} + **OH**	 **hydroxyl group** (-OH) bound to a saturated C-atom	 ethanol		-ol
Carboxylic acids $C_nH_{2n}O_2$	 **carboxyl group** (**carbonyl** + hydroxyl = carboxyl) = (carbon oxygen double bond with -OH)	 ethanoic acid		-anoic acid

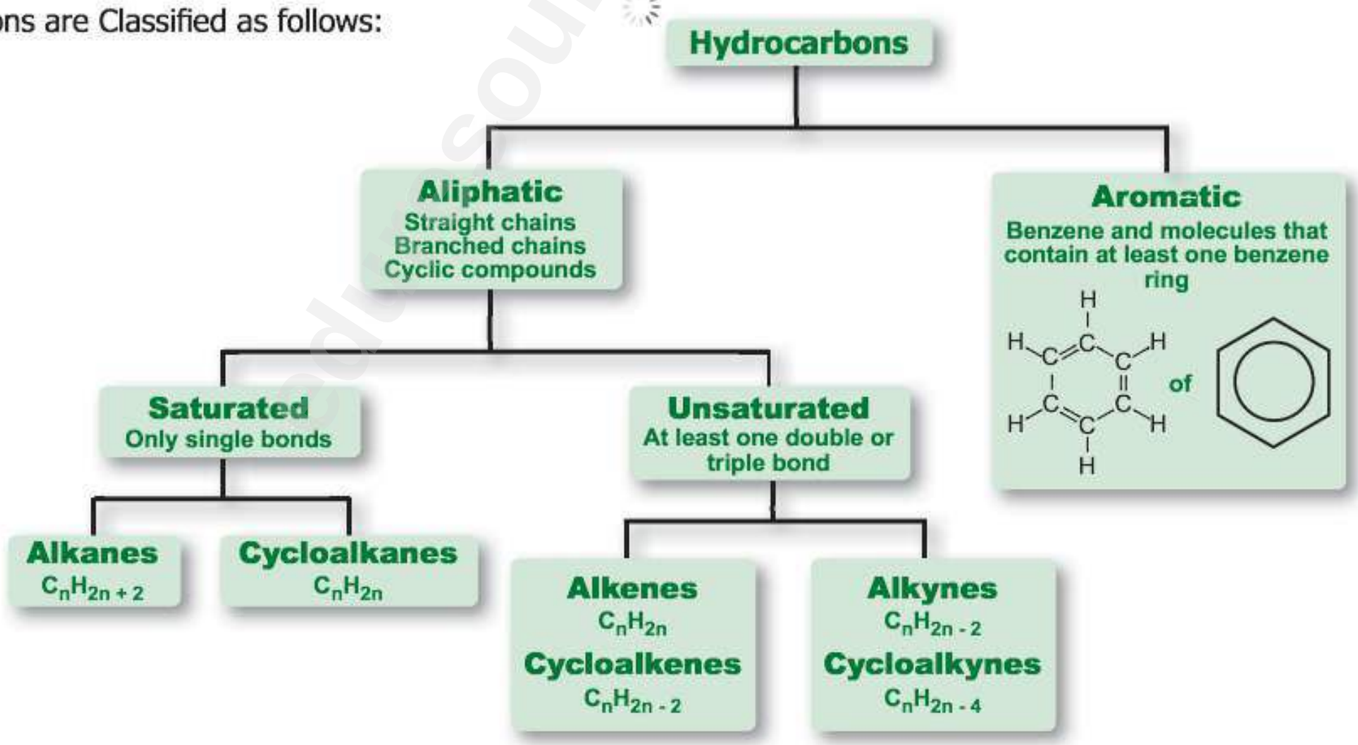
Homologous series and gen. formula	Functional group	Example Structural formula and name	Ball and stick model	Name ends with
Esters $C_nH_{2n}O_2$	 (carbonyl group + O between two C-atoms)	 ethyl methanoate		-oate
Aldehydes $C_nH_{2n}O$	 **Formic group** (carbonyl group + H on end)	 ethanal		-anal
Ketones $C_nH_{2n}O$	 **carbonyl group** (carbon oxygen double bond) between two C-atoms	 propanone		-anoon

▪ Classification of organic compounds

Organic compounds are generally classified as aliphatic or aromatic. Aromatic compounds contain one or more ring structures which consist of five or six C-atoms with alternate double bonds. If it is a hexagonal ring, it is known as arenes or benzene rings. They have typically, usually pleasant smells. All other organic compounds are aliphatic. If compounds consist only of carbon and hydrogen, they are known as **hydrocarbons**.

Hydrocarbons are organic compounds that consist only of carbon and hydrogen.

Hydrocarbons are Classified as follows:

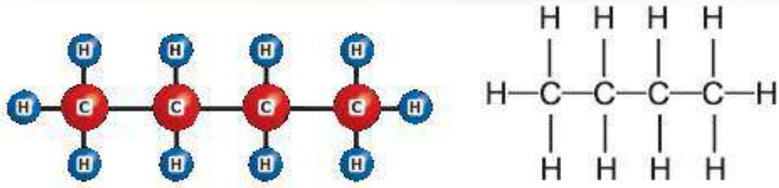


Our study of hydrocarbons would be restricted to acyclical saturated hydrocarbons (alkanes) and unsaturated hydrocarbons (alkenes and alkynes).

• Saturated hydrocarbons

The group of aliphatic hydrocarbons with only **single covalent bonds between the C-atoms** are named **alkanes** and is called **saturated hydrocarbons**.

Saturated hydrocarbons are organic compounds consisting of only carbon and hydrogen, with no multiple bonds between C-atoms in their hydrocarbon chains (only single covalent bonds).

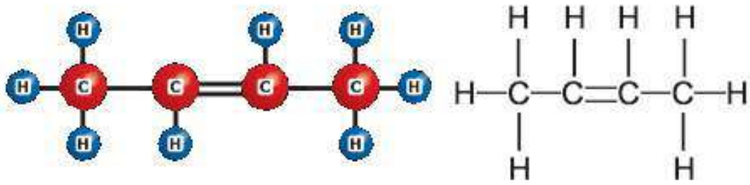


Butane (an alkane) is a saturated hydrocarbon.

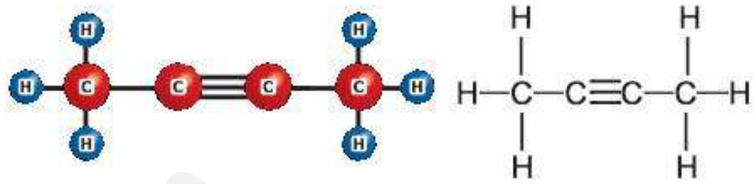
• Unsaturated hydrocarbons

The group of aliphatic compounds with **double covalent bonds between two C-atoms** are named **alkenes**, while the group of aliphatic compounds with **triple covalent bonds between the C-atoms** are named **alkynes**. **Alkenes** and **alkynes** are **unsaturated hydrocarbons**.

Unsaturated hydrocarbons are organic compounds, with one or more multiple covalent bonds (double or triple bonds) between the C-atoms in the hydrocarbon chains.



But-2-ene (an alkene) is an unsaturated hydrocarbon.



But-2-yne (an alkyne) is an unsaturated hydrocarbon.

• Test for saturated and unsaturated hydrocarbons

(1) With bromine ($Br_2(aq)$)

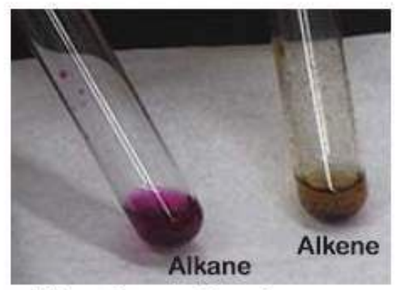
- Add a few drops of bromine water which is an orange-brownish of colour, to a compound which is tested for being saturated (alkane) or unsaturated (alkene or alkyne).
  Shake the solution.
- If the orange-brownish colour immediately vanish (discolours immediately, the solution is an unsaturated hydrocarbon (alkene or alkyne))
- If the orange-brownish colour does not vanish immediately (not discolour immediately), it is a saturated hydrocarbon (alkane). It will however discolour with time.



The alkene discolours bromine water .

(2) With potassium permanganate ($KMnO_4(aq)$)

- Add a few drops of potassium permanganate solution which is purple in colour, to a compound which is tested for being saturated or unsaturated. Shake the solution.
- If the purple colour disappears (discolours immediately and forms a brownish precipitate) the solution is an unsaturated hydrocarbon (alkene or alkyne).
- If the purple colour does not disappear (not discolour immediately), it is a saturated hydrocarbon (alkane). It will however discolour over time.



The alkene discolours a potassium permanganate solution.

ISOMERS

Most organic compounds have a molecular formula which corresponds with that of another compound. This property is known as **isomerism** and these different compounds with the same molecular formula are known as **isomers** There are different types of **isomers** like structural and stereoisomers, but in this course we will only discuss structural isomers.

▪ Structural isomers

Structural or constitutional isomers are organic molecules with the same molecular formula, but different structural formulae.

Structural isomers (also known as constitutional isomers) have:

- the same molecular formula, but differ in the way the atoms are arranged in the molecule thus their structural formulae differ.
- different IUPAC names (International Union of Pure and Applied Chemistry)
- the same or different functional groups
- different physical properties such as melting and boiling points.
- the same or different chemical properties. They may react similarly or totally different during a chemical reaction, depending on the type of functional group.

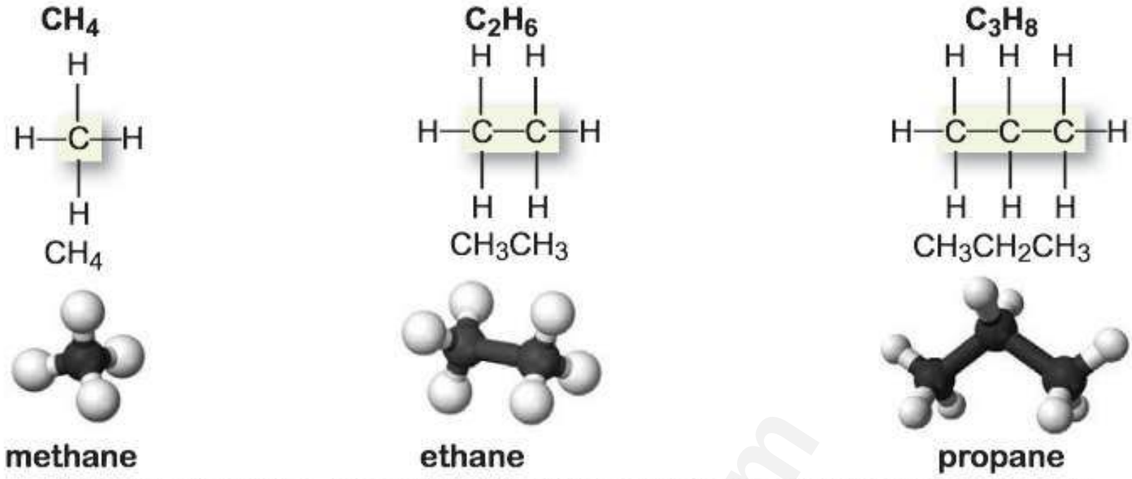
Structural isomers that contain the same functional group

1. Chain isomers

Chain isomers are compounds with the same molecular formula, but have different arrangements of the carbon chain within the molecule.

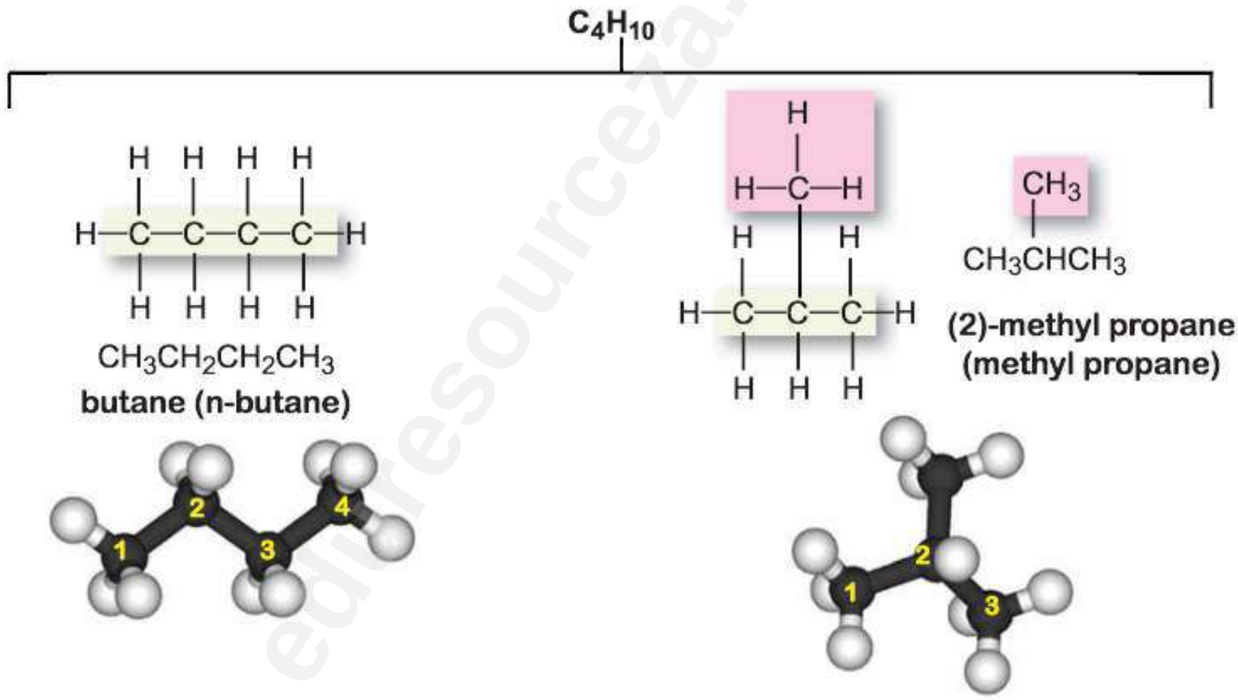
- ***Chain isomers in alkanes***

For the first three members of the alkane homologous series, methane, ethane and propane, there is only one arrangement of C-atoms and H-atoms.



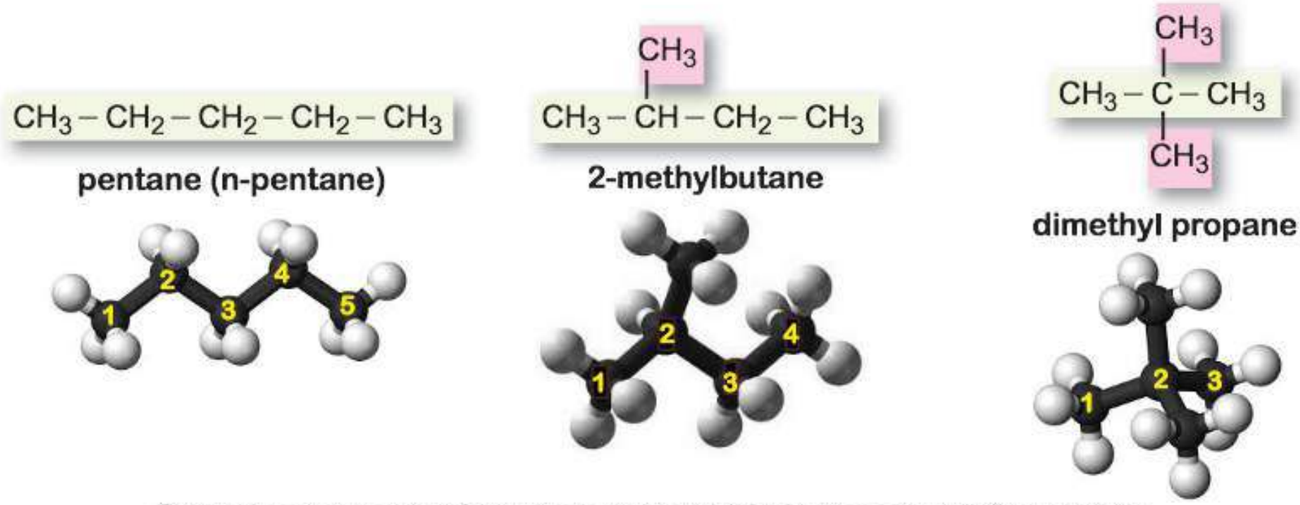
Molecular formulae, structural formulae, condensed structural formulae and the ball-and-stick models for methane, ethane and propane.

When *four C-atoms* are present, two different structural formulae could be obtained. One of them is butane, that consists of a ***straight*** *carbon chain*; the other one is methyl propane which consists of a ***branched*** *carbon chain*.



Molecular formulae, structural formulae, condensed structural formulae and the ball-and-stick models for butane and (2)-methyl propane.

Butane and 2-methyl propane are typical **chain isomers** of each other. Chain isomers differ in the arrangement of C-atoms within the molecule. Chain isomers always consist of one long straight chain isomer, and one or more branched chain isomers. An example is C_5H_{12}.



Condensed structural formulae and the ball-and-stick models for pentane, 2-methylbutane and dimethyl propane.

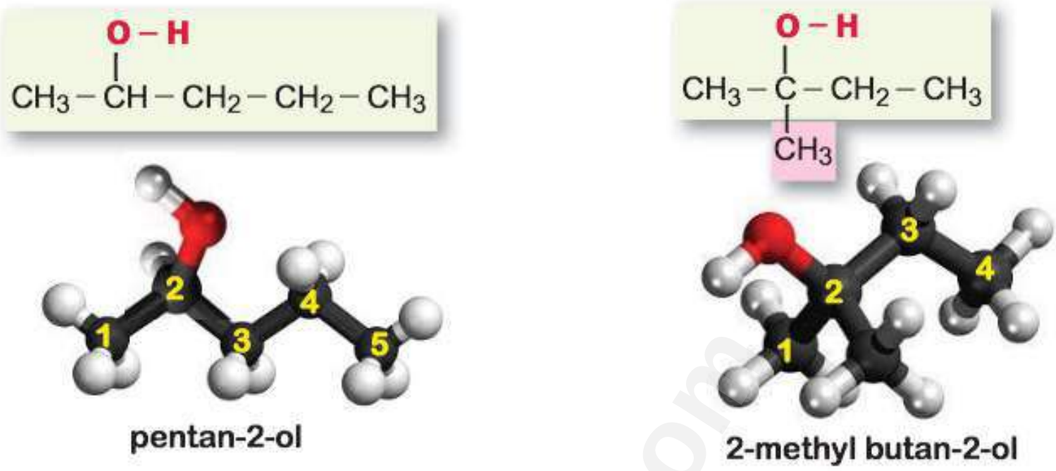
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Thus, when four or more C-atoms are present, chain isomers can be formed. The more C-atoms in the compounds, the more chain isomers could be formed as seen in the following table:

Formulae	C_4H_{10}	C_4H_{12}	C_6H_{14}	C_7H_{16}	C_8H_{18}	C_9H_{20}	$C_{10}H_{22}$	$C_{20}H_{42}$	$C_{30}H_{62}$
Number isomers	2	3	5	9	18	35	75	366 319	more than 4 000 trillion

• *Chain isomers in other homologous series*

To be classified as chain isomers, the ***functional group must always bond to the same C-atom*** in the main chain. For example, the alcohol with molecular formula $C_5H_{12}O$ (or $C_5H_{11}OH$) both has two chain isomers.



pentan-2-ol 2-methyl butan-2-ol

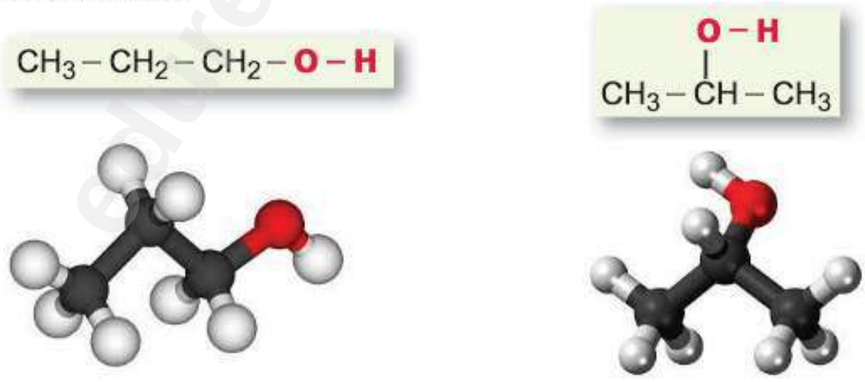
Condensed structural formulae and ball-and-stick models for the chain isomers of $C_5H_{12}O$ (or $C_5H_{11}OH$).

2. Positional isomers

Positional isomers are organic compounds with the same molecular formula and carbon parent chain, but different positions of the branches, substituents or functional groups on the parent chain.

In positional isomers the parent chain stays unchanged, but the branches, substituents or functional groups change their positions on the parent chain. Positional isomers are found in organic compounds that have three or more C-atoms in the parent chain.

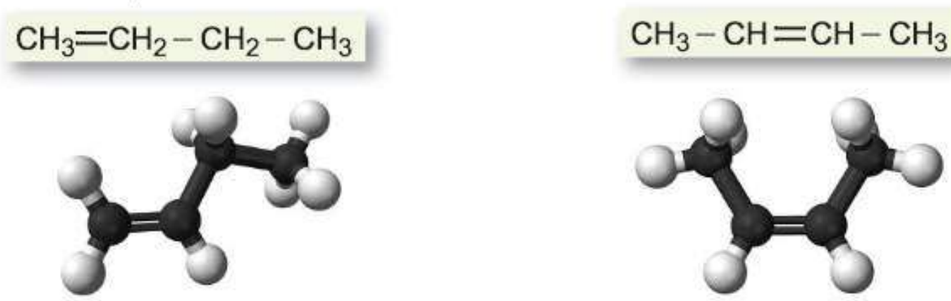
Propan-1-ol and propan-2-ol for example have the same molecular formula C_3H_8O (or C_3H_7OH) and parent chain, but the hydroxyl group (-**OH** functional group) are at different positions in the carbon parent chain. Propan-1-ol and propan-2-ol are thus positional isomers.



propan-1-ol propan-2-ol

Condensed structural formulae and the ball-and-stick models of the positional isomers of C_3H_8OH.

The alkene C_4H_8 also has two positional isomers.



but-1-ene but-2-ene

Condensed structural formulae and the ball-and-stick models of the positional isomers of C_4H_8.

In general, chain isomers and positional isomers which contain the same functional group, have **the same chemical properties**, but **different physical properties** as observed in the difference in e.g. boiling points (This is discussed further on in this chapter)

	Name	Boiling point (°C)
Chain isomers of C_4H_{10}	Butane	-0,5
	2-methylpropane	-11,7
Chain isomers of C_5H_{12}	Pentane	36,5
	2-methylbutane	27,9
	2,2-dimethylpropane	9,5
Chain isomers of C_3H_7CHO	Butanal	75
	2-methylpropanal	63
Chain isomers of C_3H_7OH	Propan-1-ol	97,2
	Propan-2-ol	82,4

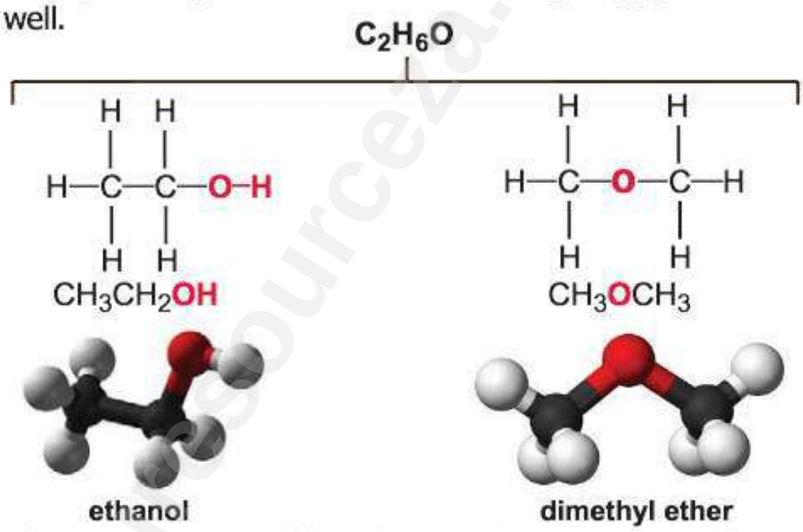
Boiling points of some structural isomers.

Structural isomers which contain different functional groups

3. Functional isomers

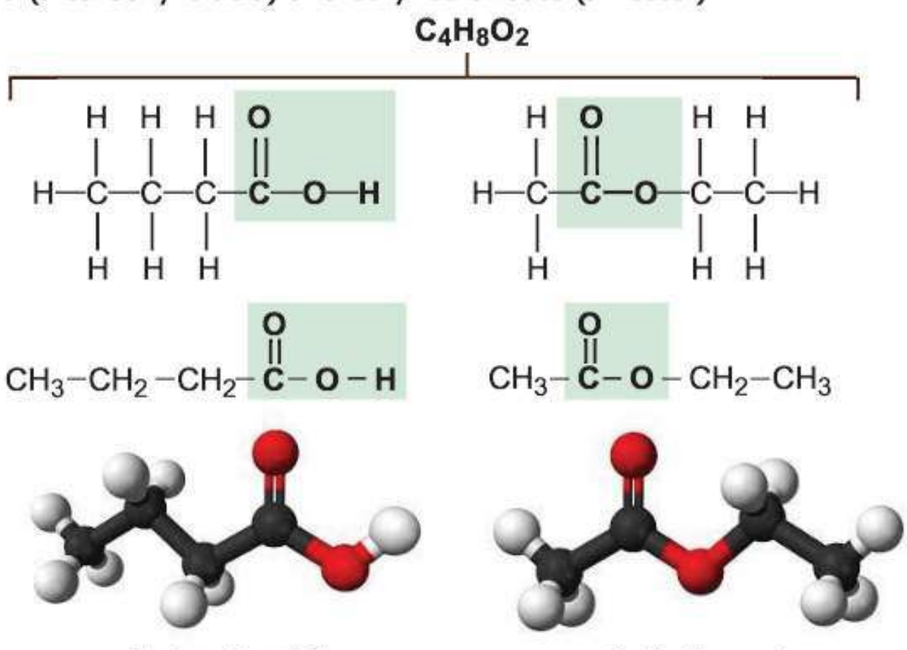
Functional isomers are compounds with the same molecular formula, but different functional groups.

The molecular formula C_2H_6O can represent an **alcohol,** ethanol (CH_3CH_2OH) or an **ether,** dimethyl ether (CH_3OCH_3). Both have the same molecular formula, but different functional groups. In the alcohol molecule, the hydroxyl group (-**OH**) is bound to a C-atom, while in the ether the oxygen atom (**O**) is bonded to two C-atoms. Where positional isomers differ only in the position of the functional group(s), functional isomers belong to ***different homologous series*** as well.



Molecular formulae, structural formulae, condensed structural formulae and the ball-and-stick models for the functional isomers of C_2H_6O.

Two other functional isomers with the same molecular formula ($C_4H_8O_2$), but different functional groups are, for example, butanoic acid (a carboxylic acid) and ethyl ethanoate (an ester).



Molecular formulae, structural formulae, condensed structural formulae and the ball-and-stick models for the functional isomers of $C_4H_8O_2$.

Because functional isomers belong to different homologous series, they too have different physical and chemical properties (as will be discussed further in the chapter).

Name	Boiling point (°C)	Density ($g \cdot cm^{-3}$)	Solubility in water
Butanoic acid	164	0,964	Very soluble
Ethyl ethanoate	77,1	0,901	Partly soluble

Some physical properties of the functional isomers of $C_4H_8O_2$.

EXPERIMENT 1

Part 1 : Test for saturated an unsaturated hydrocarbons

Purpose: To investigate the reactions of alkanes and alkenes with bromine water

Method:

1. Pour approximately 5 cm^3 cyclohexane and 5 cm^3 cyclohexene in 2 separate test tubes.
2. Add approximately 20 drops of bromine water drop for drop to each of the test tubes
3. Shake the test tubes and observe any colour change. (Place the test tubes in direct sunlight if no colour change is observed. The reaction may take a while, so careful observation is imperative. Some of the colour changes may take overnight to occur.)
4. Again pour ± 5 cm^3 cyclohexene and 5 cm^3 cyclohexane in 2 new separate test tubes.
5. Add ± 20 drops of potassium permanganate drop for drop to each of the test tubes
6. Shake the test tubes and observe any colour change.

Chemicals needed

- Cyclohexane (C_6H_{12})
- Cyclohexene (C_6H_{10})
- Bromine water
- Potassium permanganate solution ($KMnO_4$ (aq))

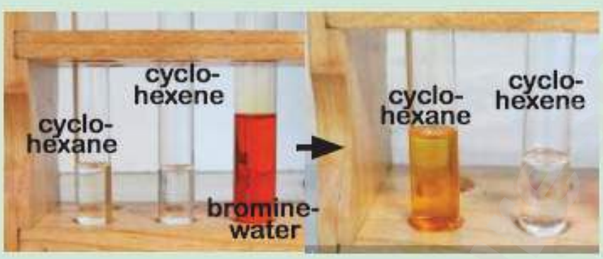
Apparatus needed

- Four test tubes
- Test tube holder
- 3 Medicine drippers

Safety!



- Wear an overall, gloves and safety goggles at all times.
- Bromine is extremely poisonous. Work with diluted solution.
- Work very carefully that no bromine gas inhalation takes place.
- Both cyclohexane and cyclohexene are flammable.
- Cyclohexene has an irritating odor and can irritate the eyes.
- Potassium permanganate is a strong oxidizing agent and harmful to the environment.
- Work in well-ventilated room in a vapor hood.



The reaction between an alkane and alkene with bromine water .



The reaction between an alkane and alkene with a potassium permanganate solution.

Observations:

Write your observations during the course of this experiment.

_____

_____

_____

_____

Conclusions:

Write a short conclusion based on the observations in this experiment.

_____

_____

_____

_____

_____

Part 2 : Prepare an alkyne and test it's saturation

Purpose: To prepare an alkyne and to determine its saturation.

Method:

1. Prepare ethyne by slowly adding water to calcium carbide granules in a vacuum flask with a rubber tube and then seal the flask with a rubber stopper.
2. Place the rubber tube in a test tube with bromine water or a beaker that contains a potassium permanganate solution, as shown in the figure.
3. Observe what happens when the formed ethyne gas is bubbled through the solution in the test tube or beaker.

Chemicals needed

- Bromine water(Br (aq))
- Beaker with a Potassium -permanganate solution ($KMnO_4(aq)$)
- Calcium carbide ($CaC_2(s)$)
- Water

Apparatus needed

- Vacuum flask with rubber tube
- Rubber stopper
- Test tube rack
- Test tube
- Glass beaker

Observation:

Write your observations during the course of this experiment.



Preparation of an alkyne (ethyne) and testing its saturation.

Conclusions:

Write a short conclusion based on the observations in this experiment.

Questions:

1. Write down a balanced chemical equation of the preparation of ethyne (C_2H_2) from calcium carbide and water. (Tip: the products are ethyne and calcium hydroxide)

2 How does the reactivity of ethyne compare to that of the alkanes and alkenes? Is ethyne saturated or unsaturated?

Exercise 1 ORGANIC MOLECULAR STRUCTURE

1. What is **organic chemistry**?

2. What makes carbon so unique to form thousands of organic structures?

3. Distinguish between **general formula**, **molecular formula**, **condensed structural formula** and **structural formula**. Give an example of each.

- **general formula**:
- **molecular formula**:
- **condensed structural formula:**
- **structural formula**:

4. Explain the following terms in your own words:

4.1 Functional group:

4.2 Homologous series:

5. Identify the group of organic compounds that contain each of the following groups:

5.1 Hydroxyl group bonded to a carbon chain.

5.2 Carbon-carbon double bond.

5.3 Carbonyl group bonded to a H-atom at the end of a carbon chain.

5.4 One or more halogen atoms bonded to C-atoms.

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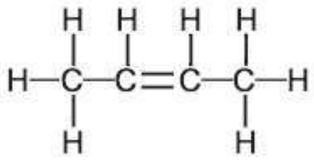
5.5 Carbon-carbon single bond. _____

5.6 Carbon-carbon triple bond. _____

5.7 Carboxyl group bonded to a carbon chain. _____

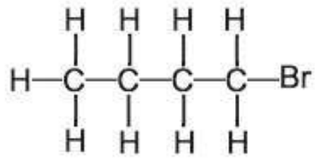
5.8 Carbonyl group between two C-atoms. _____

6. Study the following organic compounds:
   (1) Write down the functional group for each of the compounds.
   (2) Write the homologous series to which each of the compounds belong.

6.1 

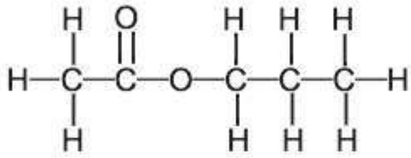
(1) _____

(2) _____

6.2 

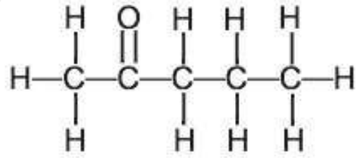
(1) _____

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6.3 

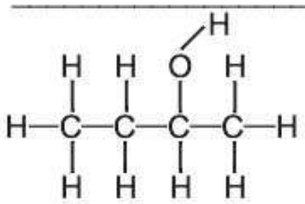
(1) _____

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6.4 

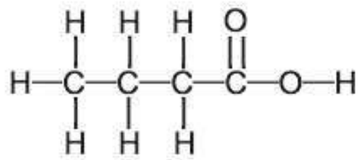
(1) _____

(2) _____

6.5 

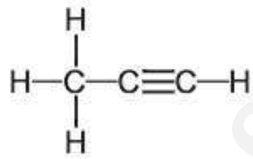
(1) _____

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6.6 

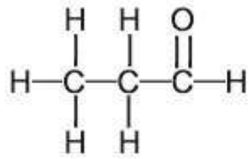
(1) _____

(2) _____

6.7 

(1) _____

(2) _____

6.8 

(1) _____

(2) _____

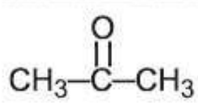
7. Classify the following molecules according to their functional groups:

7.1 $CH_3CH_2CH{=}CHCH_3$

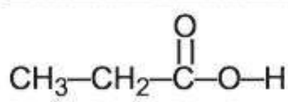
_____

7.2 $CH_3CO_2CH_2CH_3$

_____

7.3 

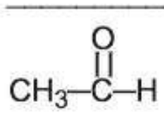
_____

7.4 

_____

7.5 $CH_3CH_2C\ell$

_____

7.6 

_____

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8. Write down the homologous series to which each of the compounds belong:

8.1 C_3H_4 _____

8.2 C_4H_{10} _____

8.3 C_2H_5Br _____

8.4 C_2H_5OH _____

8.5 $C_3H_6O_2$ _____

8.6 C_3H_6O _____

9. What is a hydrocarbon?

_____

10. Distinguish between saturated and unsaturated hydrocarbons and give examples.

_____

_____

_____

_____

_____

11 Shortly describe an experiment to distinguish between a saturated and an unsaturated hydrocarbon.

_____

_____

_____

_____

_____

12. What is meant by the term "**structural isomers**"?

_____

_____

13. 13.1 Distinguish between **chain** isomers, **positional** isomers and **functional** isomers.

- **chain** isomers: _____

_____

- **positional** isomers: _____

_____

- **functional** isomers: _____

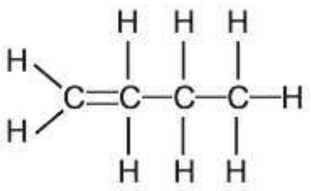
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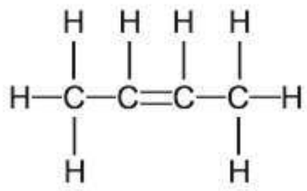
13.2 Butene has the molecular formula of C_4H_8 and the following isomers.





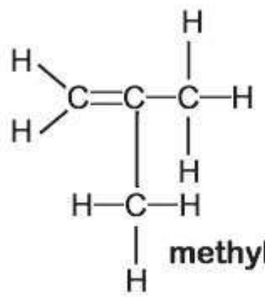
but-1-ene





but-2-ene



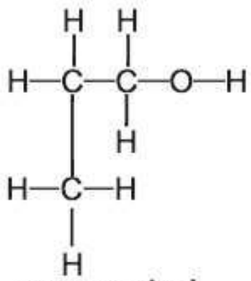


methyl propene

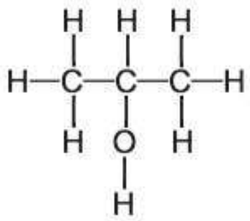
13.2.1 What type of isomers are but-1-ene and but-2-ene? _____

13.2.3 What type of isomers are methyl propene and but-1-ene? _____

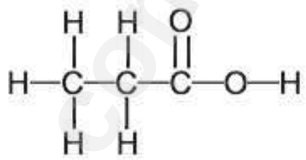
14. Consider the following six organic compounds:



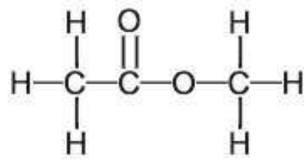
propan-1-ol



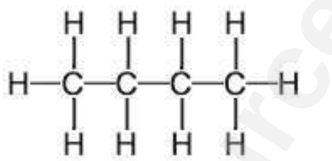
propan-2-ol



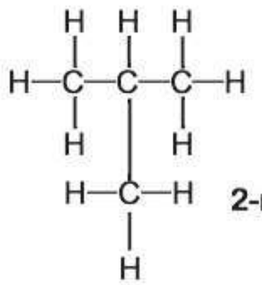
propanoic acid



methyl ethanoate



butane



2-methylpropane

14.1 Write the homologous series to which each of these compounds belong.

propan-1-ol and propan-2-ol _____

propanoic acid _____

methyl ethanoate _____

butane and 2-methyl propane _____

14.2 Which of these compounds are **chain** isomers? Explain your answer.

_____

_____

14.3 Which of these compounds are **functional** isomers? Explain your answer.

_____

_____

14.4 Which of these compounds are **positional** isomers? Explain your answer.

_____

_____

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IUPAC NAMING AND FORMULAE

1. ALKANES - as saturated hydrocarbons

The **alkanes are saturated hydrocarbons** (contains only carbon and H-atoms) with only **single covalent bonds between the C-atoms**. The functional group of alkanes are single carbon-carbon bonds and the suffix of alkanes is **-ane**. The alkanes form a homologous series (family of organic compounds), which can be represented by the general formula C_nH_{2n+2} with "**n**" an integer indicating the number of C-atoms present in the molecule. The number of H-atoms present in an alkane is always twice the number of C-atoms plus extra two hydrogens, e.g. C_4H_{10}, C_5H_{12} and C_6H_{14}. Each following member of the alkanes differs only with a **-CH_2-**group. The simplest alkanes are **methane**, **ethane** and **propane**.

- **Structure of the alkanes**

1. The **first member** (simplest) of the **alkanes** is **methane** with only one C-atom present in the molecule.

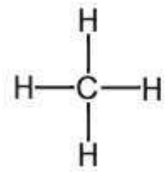
   A **model** of the **methane molecule** is:

   with **molecular formula**: CH_4

   and **condensed structural formula**: CH_4

   with **structural formula**:

2. The **second member** of the **alkanes** is **ethane**

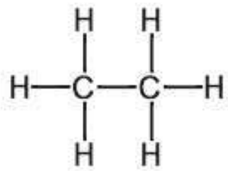
   A **model** of the **ethane molecule** is:

   with **molecular formula**: C_2H_6

   and **condensed structural formula**: CH_3CH_3 or $CH_3—CH_3$

   with **structural formula**:

3. The **third member** of the **alkanes** is **propane**.

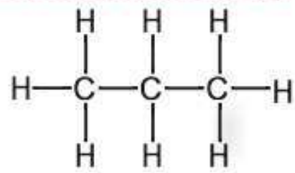
   A **model** of the **propane molecule** is:

   with **molecular formula**: C_3H_8

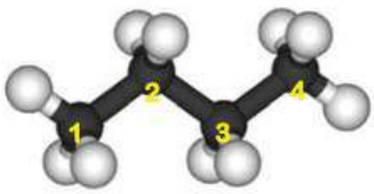
   and **condensed structural formula**: $CH_3CH_2CH_3$ or $CH_3—CH_2—CH_3$

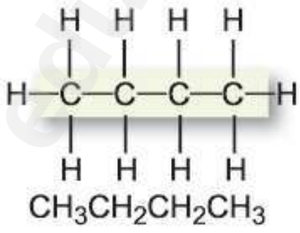
   with **structural formula**:

4. **Alkanes** with **four or more C-atoms present**, form **structural isomers.**

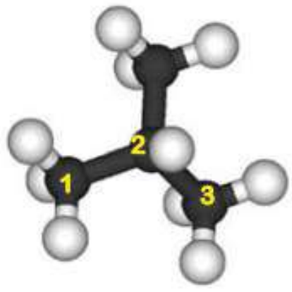
   For example: the structural isomers of the alkane with **molecular formula C_4H_{10}**, is:

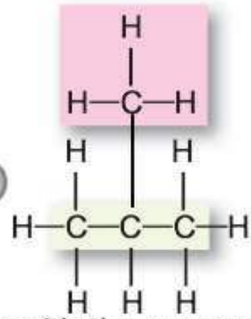
   

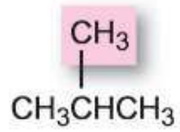
   

   $CH_3CH_2CH_2CH_3$

   butane (n-butane)

   2-methylpropane (methylpropane)

   These two structural isomers are **chain isomers**, which are compounds with the same molecular formula, but different arrangements of C-atoms within the molecular structure.

In ethane, propane and the rest of the alkanes, the C-atoms are bonded in a chain. These alkanes are known as **normal alkanes** or **n-alkanes**. The carbon chains of n-alkanes are in reality not straight chains, but form a zigzag pattern of C-atoms. This is the result if the C-atoms are bonded with only single bonds and arranged in a tetrahedral pattern around the C-atom. We say the geometry (spatial form) is tetrahedral. The tetrahedral geometry of carbon is illustrated in the three dimensional model of methane in figure 1. The three dimensional models of propane and butane show the zigzag pattern of the carbon chain and the C-C- bonding angles of 109.5 ° of a regular tetrahedron can be seen in figure 2.

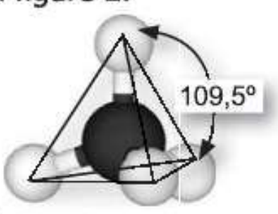


Figure 1 : ***Tetrahedral geometry of methane.***

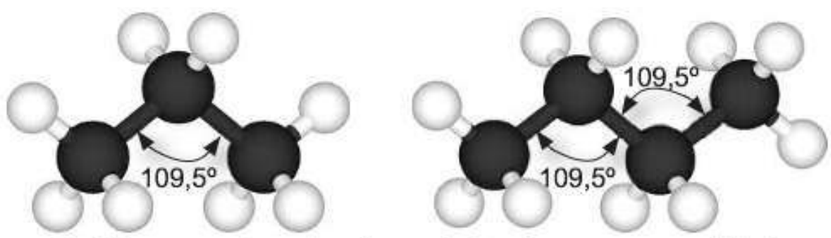
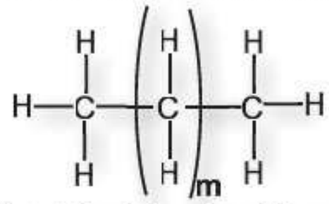


Figure 2 : ***The geometry of carbon chains in propane and butane.***

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Condensed structural formulae for the n-alkanes can also be written in an abbreviated form, e.g. the structural formula of n-pentane contains three **-CH_2-**groups (**methylene** groups) in the middle of the chain. They can be grouped together, so that the structural formula could be written as **$CH_3(CH_2)_3CH_3$**.

The long chain n-alkanes with three or more C-atoms can in general be presented by the following *abbreviated structural formula* and *abbreviated condensed formula* as follows where **m** is an integer.



abbreviated structural formula

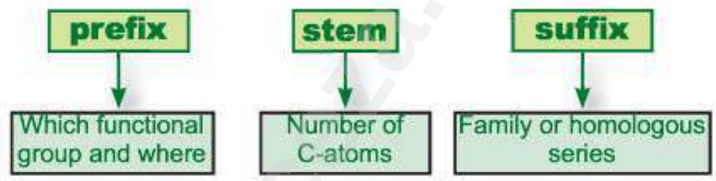
$CH_3(CH_2)_mCH_3$

abbreviated condensed formula

• IUPAC Nomenclature

The first rules for a generally more usable system of **nomenclature** (naming) for organic compounds were laid down in 1892 at an international conference. Revision and expansion of the nomenclature rules are currently controlled by the *Union of Pure and Applied Chemistry*. This system is referred to as the Geneva or **IUPAC system**, also known as the **systematic name**.

The **IUPAC system** (system of naming or labelling) uses three parts to name organic compounds: the prefix, stem and suffix. The name describes exactly of which elements and groups a compound consist of and how they are arranged in the compound. The name consists of a **prefix** (a beginning), a **stem** (a middle part) and a **suffix** (an end). The stem indicates the number of C-atoms in the parent chain of the molecule. The suffix indicates which functional group(s) are present in the molecule, i.e. the family or homologous series the compound belongs to. The prefix indicates which functional groups or any other substituents (attached parts) are attached to the main chain and where.



The following prefixes are used to indicate the number of C-atoms in the chain:

Number of C-atoms	Stem name	Number of C-atoms	Stem name
1	meth-	6	hex-
2	eth-	7	hept-
3	prop-	8	oct-
4	but-	9	non-
5	pent-	10	dec-

• Nomenclature of straight chain (normal) alkanes

The IUPAC names of the alkanes end on **–ane**. Straight chain alkanes which contain one to ten C-atoms are given in the following table

Name of alkane	Number of C-atoms	Molecular formula from C_nH_{2n+2}	Condensed structural formulae
Methane	1	CH_4	CH_4
Ethane	2	C_2H_6	CH_3CH_3
Propane	3	C_3H_8	$CH_3CH_2CH_3$
Butane	4	C_4H_{10}	$CH_3CH_2CH_2CH_3$
Pentane	5	C_5H_{12}	$CH_3CH_2CH_2CH_2CH_3$
Hexane	6	C_6H_{14}	$CH_3CH_2CH_2CH_2CH_2CH_3$
Heptane	7	C_7H_{16}	$CH_3CH_2CH_2CH_2CH_2CH_2CH_3$
Octane	8	C_8H_{18}	$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_3$
Nonane	9	C_9H_{20}	$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_3$
Decane	10	$C_{10}H_{22}$	$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_3$

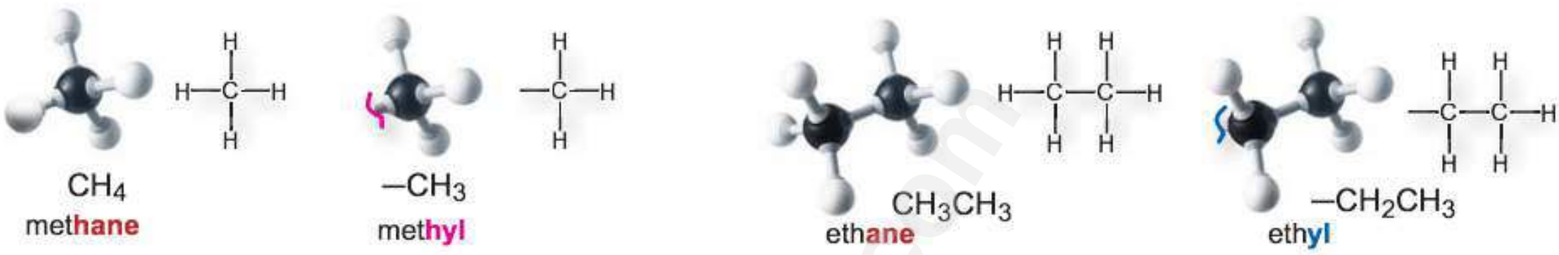
Note the pattern as the chain length increases: each following member of the alkanes differs only with a **-CH_2-**unit. The alkanes form a **homologous series** of compounds (molecules) which have the same general formula and the members of the series differ with the same group of atoms from each other. In a homologous series, all the molecules have the same functional group, but the lengths of the carbon chains differ.

• Alkyl groups and the naming of branched alkanes

A linked carbon chain is known as the **main** or **parent chain**. Often there are shorter chains which replace the H-atom on the main chain and are known as **branches** (side chains). Such a side chain is also known as a **substituent** (which means replacement). For branched alkanes, the side chain or substituent chain is known as an **alkyl** group. **An alkyl group is an alkane which has one less H-atom** (thus an alkane of which a H-atom is removed). An alkyl group is represented as an **–R** in general formulae.

The name of the alkyl group (side chain) is derived from the number of C-atoms in the side chain, i.e. it is named after the alkane stem. For one carbon it is **meth-**, for two carbons it is **eth-**, etc. The suffix **–yl** is written instead of **–ane**. A side chain (alkyl group) with one C-atom is therefore named **methyl**, while a side chain (alkyl group) with two C-atoms is therefore named **ethyl**.

The two most common alkyl groups are the one with only one C-atom present (methyl) and the one with two C-atoms (ethyl), as shown below and derived from their corresponding alkanes, methane and ethane.



The following table shows the alkyl groups with one to eight carbons:

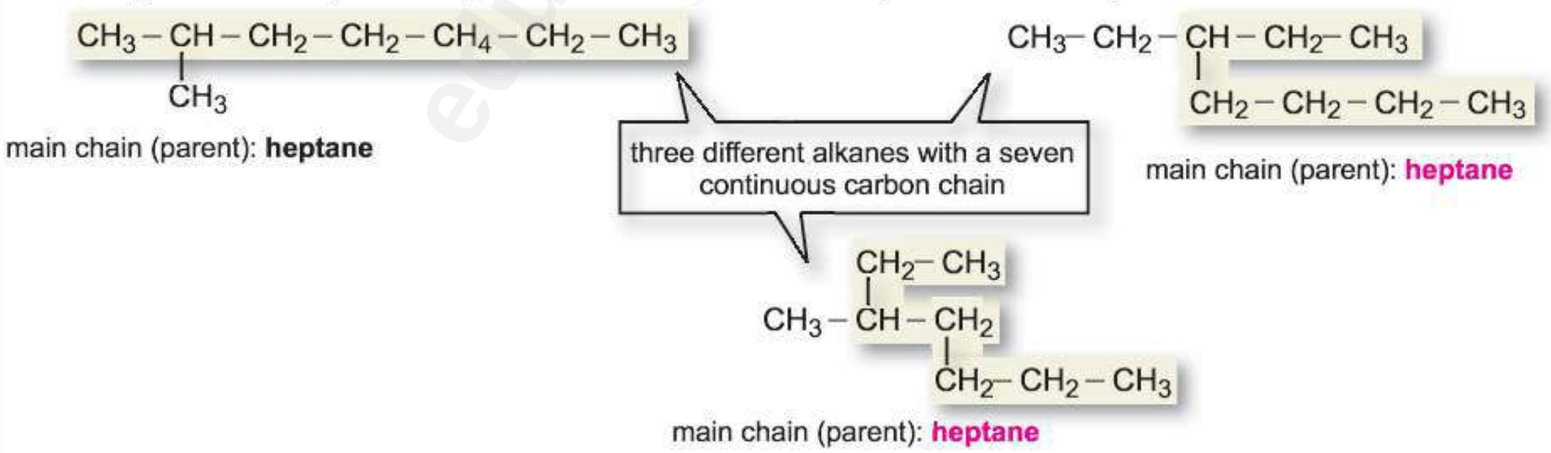
Alkyl group	Name	Alkyl group	Name
$-CH_3$	methyl	$-CH_2CH_2CH_2CH_2CH_3$	pentyl
$-CH_2CH_3$	ethyl	$-CH_2CH_2CH_2CH_2CH_2CH_3$	hexyl
$-CH_2CH_2CH_3$	propyl	$-CH_2CH_2CH_2CH_2CH_2CH_2CH_3$	heptyl
$-CH_2CH_2CH_2CH_3$	butyl	$-CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_3$	octyl

The naming of organic compounds is a step-by-step process. If you follow the steps, the correct IUPAC name of the compound can be determined. Chemists universally will then know what is implied! Let us see how it works.

The steps

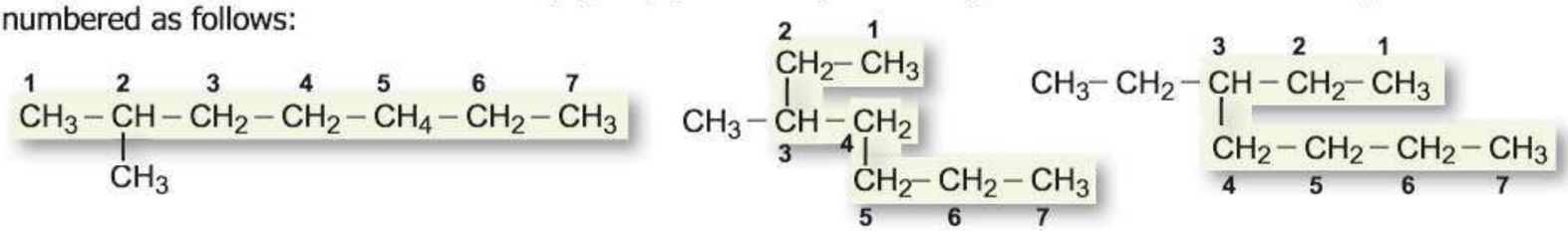
1. ***Find the longest continuous chain of C-atoms in the molecule***

This forms the main chain (or parent chain). Name the chain according to the number of C-atoms it consists of. The longest chain may not always be so obvious, sometimes you will need to go "around corners".



2. ***Number the C-atoms in the main chain to give the alkyl group (substituent) the lowest number***

To determine the position of the alkyl group (side chain or substituent) we number the C-atoms in the main chain. Start at the end closest to an alkyl group (side chain). According to this rule the three examples below are numbered as follows:



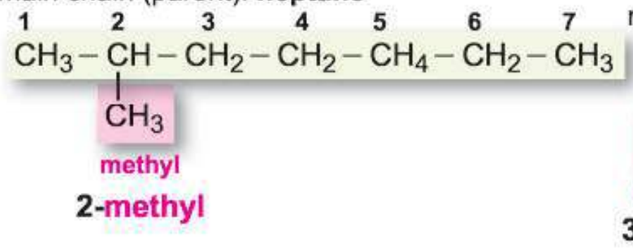
An alkyl group (side chain or substituent) cannot exist or be attached to the first or the last C-atom in a main chain! Furthermore the side chain must always be shorter than the main (parent) chain.

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3. ***Name the alkyl group and write down the name of the compound.***

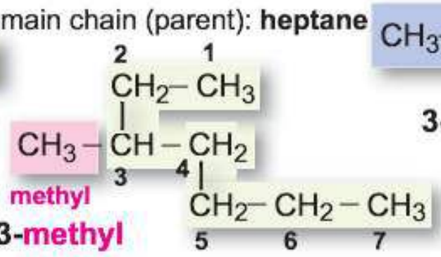
- Show the position and name of the alkyl group (branch), with a number followed by a hyphen (-) in front of the alkyl group name.

main chain (parent): **heptane**



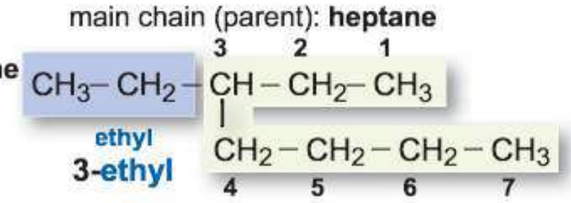
2-methyl

main chain (parent): **heptane**



3-methyl

main chain (parent): **heptane**



3-ethyl

- The name of each compound is thus as follow:

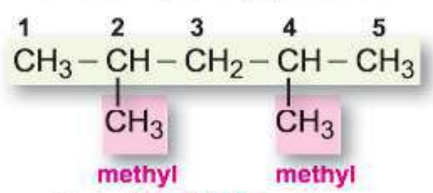
2-methylheptane **3-methylheptane** **3-ethylheptane**

4. ***If two or more identical alkyl groups (two identical substituent groups) are present***:

- If two or more identical alkyl groups are present, a suitable Greek prefix is used to indicate the number of identical groups present.
- Apart from that, each alkyl group is awarded a number depending on its position on the main/parent chain. These numbers which indicate positions are separated by commas, preceded by the prefix, (di-, tri, tetra, etc.)
- Numbers are separated from words by hyphens.
- If two identical alkyl groups are attached to the same C-atom, the number is used twice.

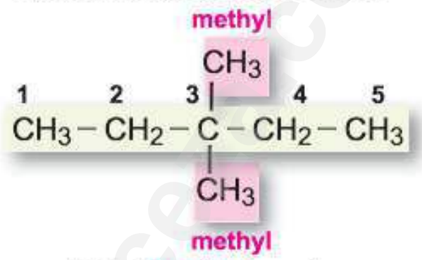
Greek prefixes
1 - mono
2 - di
3 - tri
4- tetra

main chain (parent): **pentane**



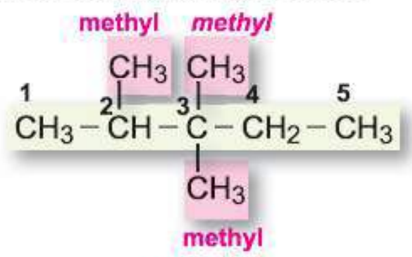
2,4-dimethylpentane

main chain (parent): **pentane**



3,3-dimethylpentane

main chain (parent): **pentane**



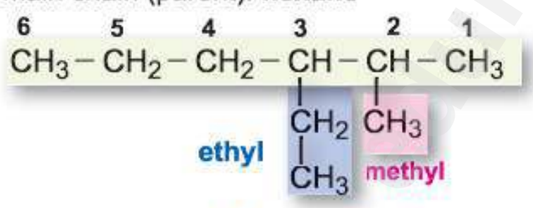
2,3,3-trimethylpentane

- Note that the prefix di- must always be accompanied by two numbers, tri- with three numbers, etc. even if the same number is repeated, e.g. 3,3-dimethylpentane.

5. ***If two different alkyl (substituent) groups are present***

- If there are two different alkyl (substituent) groups present on the same carbon chain, the groups are numbered individually and listed in alphabetical order.

main chain (parent): **hexane**

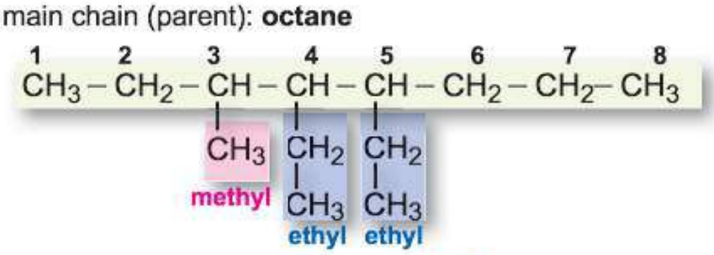


3-ethyl-2-methylhexane

Note: ethyl is before methyl in the alphabet; thus it is named first.

- The prifix (di-,tri ect.) are not considered when the alphabetical order is determined.

main chain (parent): **octane**

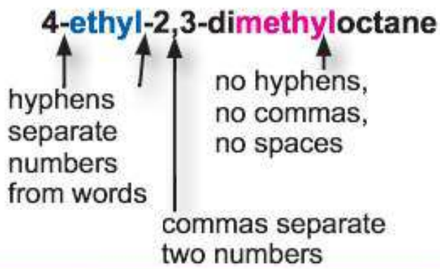


4,5-diethyl-3-methyloctane

The prifixes **di-** does not influence the alphabetical order. **Ethyl** is before **methyl**.

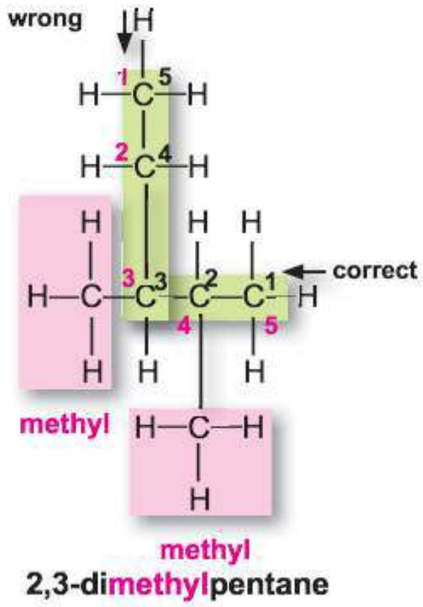
6. ***Write the name as a single word***

Punctuation is important. The name is essentially written as one word, without spaces. Numbers are separated by commas. Numbers are separated from letters by a hyphen (-).
The numbers of each branch (substituent or alkyl group) must appear in the name, even if they are the same or are connected to the same C-atom.



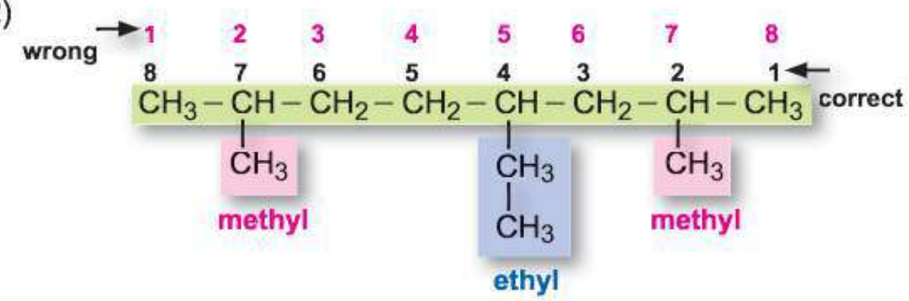
•Example

(1)



2,3-dimethylpentane

(2)



4-ethyl-2,7-dimethyloctane

Alkanes are the most **important source of fuel** in the world and are used extensively in the chemical industry.

States

The first four alkanes, C_1 - C_4 are colourless gasses. C_5 - C_{17} are colourless liquids, and alkanes with 18 and more C-atoms are waxy solids.

Solubility

Alkanes are nonpolar molecules and are insoluble in water (which is polar). They are soluble in nonpolar solvents like trichloromethane and benzene as well as other alkanes. The density of alkanes is approximately 0,7 g·dm^{-3} while the density of water is approximately 1g·dm^{-3}. Because the alkanes are less dense and insoluble in water, a mixture of an alkane and water will form two layers, with the alkane the less dense top layer. The most common example is oil that floats on water. Alkanes are therefore hydrophobic (water repellent).



Both butane and methylpropane are used in cigarette lighters and gas stoves.

Application

The human body secretes oils to maintain the moisture of the skin. Alkanes such as gasoline and paint thinners, dissolves nonpolar organic matter such as fats and oils. A person must limit contact with hydrocarbon solvents such as paint thinners, because the thinners will dissolve fats and oils in the skin and leave the skin dry and damaged.



Fuel (petrol) consists of a mixture of liquid alkanes.

Uses

- The first four alkanes: methane, ethane, propane and butane are gases at room temperature and are used as fuel to produce heat. Gas cylinders with liquid propane and butane mixture are used as fuel for heating domestically, in cigarette lighters and in gas stoves and for cooking on restaurant grills.
- Alkanes with 5-8 C-atoms (pentane, hexane, heptane and octane) are liquids at room temperature. They are highly volatile, which make them ideal to use as fuel in cars. Petrol has a low boiling point and a high vapour pressure and thus evaporates easily (highly volatile, combustible and explosive). Petrol fumes have a greater density (actually molar mass) than oxygen and may lead to asphyxiation if inhaled.
- Liquid alkanes with 9-17 C-atoms have higher boiling points and can be found in kerosene, diesel and jet fuel. Motor oil is a mixture of high molecular mass hydrocarbons and is used as laxatives and lubricants.



Solid alkanes are used as a waxy coating on fruit and as a protective layer on human skin.

- Alkanes with 18 and more C-atoms are waxy solids at room temperature. These high molecular mass alkanes are known as the paraffins and are used as a protective waxy film on fresh fruit an vegetables to insulate moisture, to slow down decay and to enhance the appearance of the fruit.
- Petroleum jelly (Vaseline) is a soft, semi-solid mixture of hydrocarbons, which form a protective layer on the skin, if applied. It is hydrophobic (repels water) and is used for minor burns or the prevention of nappy rash. The higher viscosity of Vaseline explains why it does not flow as easily as say, petrol. It should however not be applied immediately to burns, as it will form a protective layer, preventing the cooling down of the wound and thus increasing the pain.

Exercise 2 ALKANES

1. Consider the following ball and stick models of the first three **alkanes**.



1.1 What is an alkane? _____

_____

1.2 Give the general formula of an alkane: _____

1.3 Give the IUPAC names of the alkanes with the following molecular formulae:

1.3.1 C_3H_8 _____ 1.3.2 C_5H_{12} _____

1.3.3 C_8H_{18} _____

1.4 Write down the molecular formulae for each of the following alkanes:

1.4.1 ethane _____ 1.4.2 hexane _____

1.4.3 heptane _____

1.5 Complete the following molecular formulae with the number of C-atoms given:

1.5.1 C_5H____ 1.5.2 C_5H____ 1.5.3 C_5H____ 1.5.4 C_5H____

1.6 Complete the following molecular formulae with the number of H-atoms given:

1.6.1 C____H_{12} 1.6.2 C____H_8 1.6.3 C____H_{20} 1.6.4 C____H_{32}

1.7 An alkane has 15 C-atoms. How many H-atoms does it have? _____

1.8 Which of the following are alkanes? (1) C_2H_4 (2) C_5H_{10} (3) $C_{14}H_{30}$ (4) C_7H_8 (5) C_4H_{10}

_____

2. Complete the following table regarding the first eight alkanes:

Name	Molecular formula	Structural formula	Condensed structural formula

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Name	Molecular formula	Structural formula	Condensed structural formula

3. 3.1 What is a straight chain alkane (also named an n-alkane)? Make use of an example to illustrate your answer.

_____

_____

_____

_____

_____

3.2 What is a branched alkane? Make use of an example to illustrate your answer.

_____

_____

_____

_____

_____

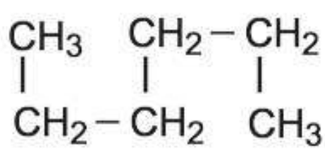
3.3 The structure of hexane can be drawn as follows: (see below) Is hexane described as a straight chain alkane or a branched chain alkane? Explain.

_____

_____

_____

_____



4. 4.1 What is an alkyl group? _____

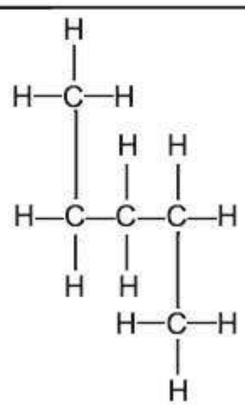
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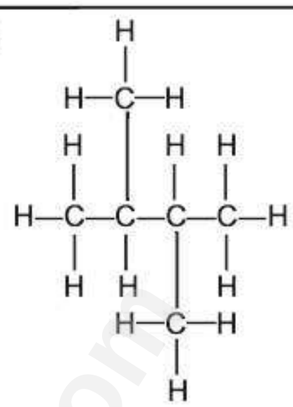
4.2 Draw the structure and give the names of the first four straight chain alkyl groups.

5. Give the IUPAC name of the following alkanes:

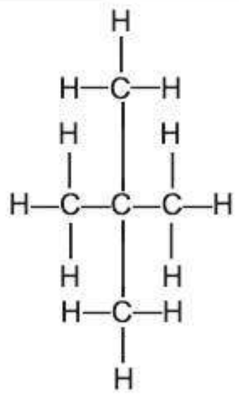
5.1



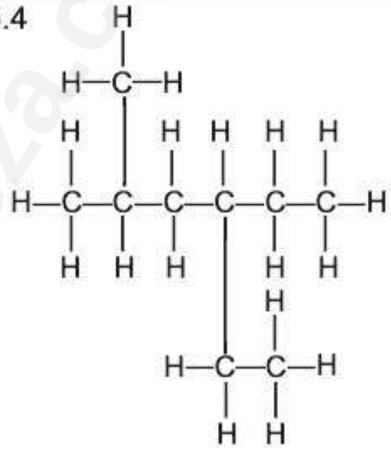
5.2



5.3



5.4



5.5 $CH_3CH_2\underset{\displaystyle CH_3}{\underset{|}{C}}HCH_3$

5.6 $CH_3CHCH_2CHCH_2CHCH_3$ (with CH_3 groups on the 2nd, 4th and 6th carbons)

5.7 $CH_2-CH_2-\underset{\displaystyle CH_3}{\underset{|}{C}}H-CH_2-CH_2-\underset{\displaystyle CH_3}{\underset{|}{C}}H_2$ (with CH_3 groups on the 2nd and 5th carbons)

5.8 $CH_3CH_2\underset{\displaystyle CH_2CH_2CH_3}{\underset{|}{C}}HCH_2CH_3$

5.9 $CH_3-CH_2-\underset{\displaystyle CH_2-CH-CH_3}{\underset{|}{C}}H-CH_2-CH_2-CH_3$ (with CH_3 on the 2nd carbon of the branch)

5.10 $\underset{\displaystyle CH_3}{\underset{|}{C}}HCH_2CH_2CH_3$ (with CH_2CH_3 on the same carbon)

5.11 $CH_3CH_2CH_2\underset{\displaystyle CH_2CH_3}{\underset{|}{C}}CH_3$ (with $CH_2CH_2CH_3$ on the same carbon)

5.12 $CH_2-CH-CH_2-CH-CH_2-CH_2$ (with CH_3 on the 2nd, CH_3-CH_3 on the 4th, CH_3 on the 5th and CH_3 on the 6th carbons)

5.13 $CH_2-CH-CH-CH-CH_2-CH_2$ (with CH_3 on the 2nd, CH_2CH_3 on the 3rd, CH_3 on the 4th and CH_3 on the 6th carbons)

5.14 $CH_3-CH-\underset{\displaystyle CH_2\ CH_2}{\underset{|}{C}}-CH_2-CH_2-CH_3$ (with CH_3 on the 2nd carbon and CH_3 on each of the two branch carbons)

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6. For the following shortened condensed formulae, give the following for each
   (1) structural formula
   (2) IUPAC name of the compound.

6.1 $(CH_3)_3CH$

6.2 $(CH_3)_2CHCH_2CH_3$

6.3 $(CH_3)_4C$

6.4 $CH_3CH_2CH(CH_3)CH_2CH_3$

6.5 $(CH_3)_2CHCH(CH_3)_2$

6.6 $(CH_3CH_2)_3CH$

6.7 $(CH_3)_2CHCH(CH_3)CH_2CH_3$

6.8 $(CH_3)_3CCH(CH_3)_2$

6.9 $CH_3CH_2C(CH_3)_2CH_2CH_3$

6.10 $CH_3C(CH_3)_2CH_2CH(CH_2CH_3)_2$

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7. Draw the structural formulae of each of the following alkanes:

7.1 2,3-dimethylpentane

7.2 2,3,4-trimethylhexane

7.3 3,3-diethylheptane

7.4 4-ethyl-3-methylheptane

7.5 3,3-diethyl-4-methylheptane

7.6 5-ethyl-2,5-dimethylheptane

7.7 3,3,5-triethyloctane

7.8 4,4-diethyl-2-methylheptane

8. Draw the condensed structural formulae of each of the following alkanes:

8.1 butane

8.2 2-methylbutane

8.3 2,4-dimethylhexane

8.4 2,2,4-trimethylhexane

8.5 3-ethylheptane

8.6 3,3,5-triethyloctane

8.7 4-ethyl-2,2-dimethylheptane

8.8 3,3-diethyl-6-methyloctane

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8.9 3,4-diethyl-6-methyloctane

8.10 3-ethyl-2,3-dimethylhexane

8.11 methylpropane

8.12 dimethylpropane

9. The next names are FAULTY. Give their correct IUPAC names.

9.1 2,2-dimethyl-6-ethylpentane _____

9.2 4-ethyl-5,5-dimethylpentane _____

9.3 3-ethyl-5,5-dimethylpentane _____

9.4 5,5,6-trimethyloctane _____

10. 10.1 What are structural isomers?

_____

_____

10.2 There are THREE isomers with the formula C_5H_{12}. Draw their **structural formula** and name them.

10.3 What type of structural isomers are named in 10.2? Explain your answer.

_____

_____

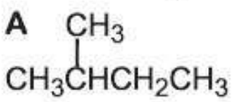
10.4 There are FIVE isomers with the formula C_6H_{14}. Draw their **condensed structural formula** and name them.

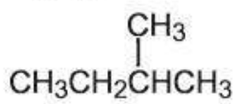
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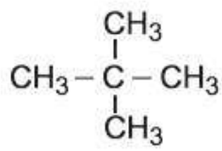
10.5 There are NINE isomers with the formula C_7H_{16}. Draw their **structural formula** and name them.

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11. All the following structures have the formula C_5H_{12}.

A


B


C


11.1 Give the IUPAC-name for each of these structures?

A : _____

B : _____

C : _____

11.2 Which of these structures represent the same molecule? Explain your answer.

_____

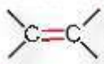
_____

11.3 What are **A** and **C** of each other? _____

2. ALKENES - as unsaturated hydrocarbons

The **alkenes** are **unsaturated hydrocarbons** with **double covalent bonds between the C-atoms**. The functional group of the alkenes is carbon-carbon double bonds and the IUPAC name of the alkenes ends on **-ene**. In each alkene there is at least one carbon-carbon double bond present. The alkenes form a **homologous series** (a family of organic compounds) which is represented by the general formula C_nH_{2n}, with "**n**" an integer and representing the number of carbons in the compound. The number of H-atoms present in is always double the number of C-atoms in a single unsaturated compound, e.g. C_4H_8, C_5H_{10} and C_6H_{12}.

• Structure of the alkenes

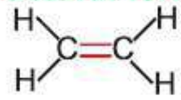
1. The **first member** of the **alkenes** or the simplest member of the alkenes is **ethene**. There is no alkene with only one carbon, as the alkenes need at least two carbons to form the  double bond.

   A **model** of the **ethene molecule** is:

   with **molecular formula**: C_2H_4

   with **structural formula**:

   and **condensed structural formula**:
   CH_2CH_2 *or* $CH_2{=}CH_2$

2. The **second member** of the **alkenes** is **propene**.

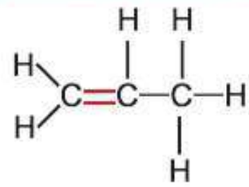
   A **model** of the **propene molecule** is:

   with **molecular formula**: C_3H_6

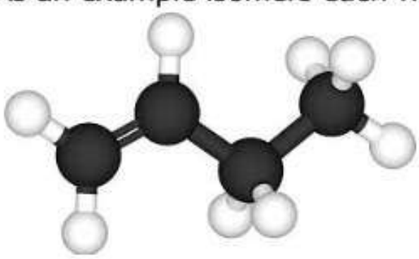
   and **condensed structural formula**:
   CH_2CHCH_3 *or* $CH_2{=}CH-CH_3$

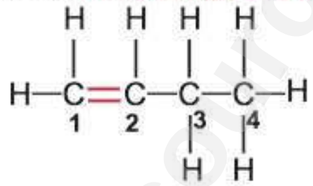
   with **structural formula**:

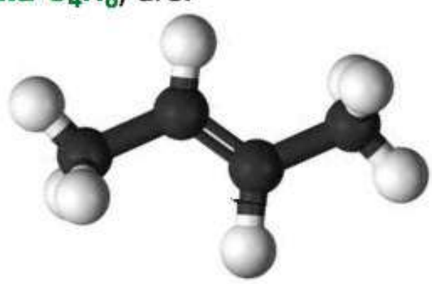
3. **Alkenes** with **four and more C-atoms** form **structural isomers**.

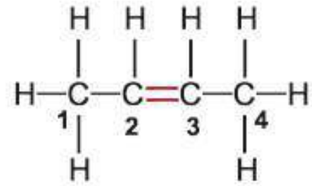
   As an example isomers each with the **molecular formula C_4H_8**, are:

   but-**1**-**ene**
   $CH_2{=}CH-CH_2-CH_3$

   but-**2**-**ene**
   $CH_3-CH{=}CH-CH_3$

These two structural isomers are named **positional isomers**, which are compounds with the same molecular formula and the same carbon parent chain, but the functional group (double bond) is situated on different positions on the parent carbon chain.

• Naming of alkenes

1. ***Find the longest continuous C-atom chain which contains the double bond***

   The longest continuous parent/stem chain which contains the double bond is chosen and the stem name are formed by replacing the suffix "**–ane**" used for alkanes with "**-ene**" for the alkenes. Thus eth**ane** becomes eth**ene**. As two C-atoms are needed to form an alkene, there is no corresponding compound for methane.

   $CH_3-CH{=}CH-CH_2-CH_3$

   5 C-atoms in the parent chain
   pent**ane** ·····→ pent**ene**

   $CH_3-CH(CH_2-CH_3)-C{=}CH_2$

   5 C-atoms in the parent chain-
   pent**ane** ·····→ pent**ene**

   $CH_3-CH_2-C(CH_2-CH_3){=}CH_2$

   4 C-atoms in the parent chain
   but**ane** ·····→ but**ene**

   Note: The parent carbon chain must contain the double bond!

2. ***Number the C-atoms in the parent chain from the side nearest to the double bond***

   The position of the double bond determines the numbering of the parent chain. For alkenes the double bond must have the smallest number possible.

   $\overset{1}{C}H_3-\overset{2}{C}H{=}\overset{3}{C}H-\overset{4}{C}H_2-\overset{5}{C}H_3$

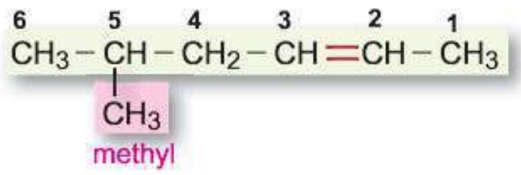
   $CH_3-\overset{3}{C}H(\overset{4}{C}H_2-CH_3)-\overset{2}{C}{=}\overset{1}{C}H_2$

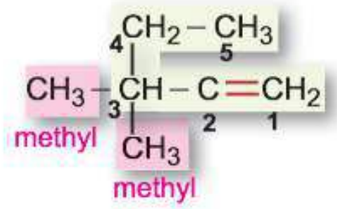
   $CH_3-CH_2-\overset{2}{C}(\overset{1}{C}H_2-CH_3){=}\overset{1}{C}H_2$

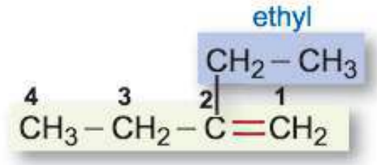
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3. ***Identify and number the substituents***

Positions of the alkyl substituents are indicated by numbers as for the alkanes. The double bond however enjoys preference in numbering of the parent chain and the alkyl groups may not necessarily have the lowest numbers. In numbering alkenes, the double bond must have the lowest possible number.

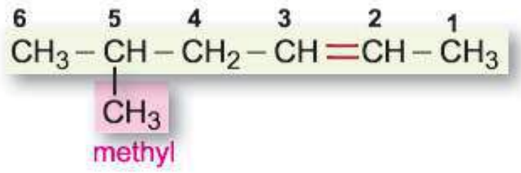




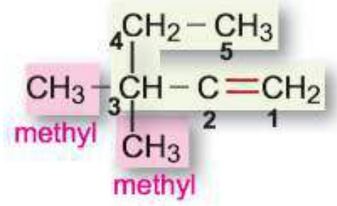


4. ***Write down the full IUPAC name***

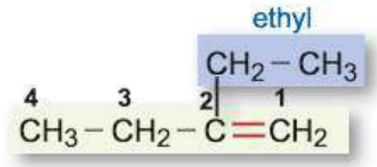
Number the substituents according to their position on the parent chain and list them alphabetically. Indicate the position of the double bond with a number between the stem name (prop-, but-, pent-, hex-) and the suffix (-ene).



5-methylhex-2-**ene**
(*or 5-methyl-2-hexene*)



3,3-dimethylpent-1-**ene**
(*or 3,3-dimethyl-1-pentene*)

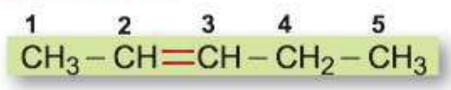


2-ethylbut-1-**ene**
(*or 2-ethyl-1-butene*)

The position of the double bond could also be indicated as follows: Instead of **but**-1-**ene** can also be written, 1-**butene**.

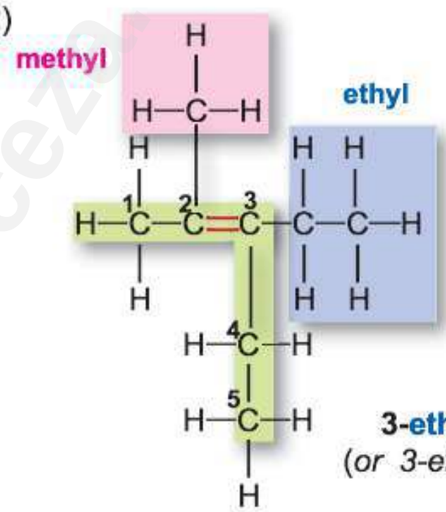
• Examples

(1)



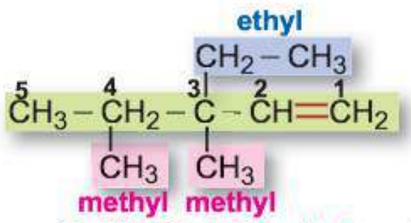
pent-3-ene
(*or 3-pentene*)

(2)



3-ethyl-2-methylpent-2-ene
(*or 3-ethyl-2-methyl-2-pentene*)

(3)



3-ethyl-3,4-dimethylpent-1-ene
(*or 3-ethyl-3,4-dimethyl-1-pentene*)

• Dienes

Alkenes that have **two double bonds** in the parent chain are called **dienes**. Depending on the relative positions of the double bonds, dienes are classified as follows:

Conjugated diene: Single and double bonds follow each other in a carbon chain.
e.g. $CH_2=CH-CH=CH-CH_3$

Isolated diene: The two double bonds are separated by three or more C-atoms.
e.g. $CH_2=CH-CH_2-CH=CH_2$

Cumulated diene: One C-atom is involved with two double bonds.
e.g. $CH_2=C=CH_2$

Rules for naming diënes

1. If two double bonds are present, the compound is a diene.
2. Choose the longest parent chain which contains the 2 double bonds.
3. Start numbering from the side which would allocate the lowest numbers to the C=C bonds
4. Separate numbers by commas and add in front of the name.
5. Substituents are named as in the alkanes.

• Examples

(1) $CH_2=C=CH_2$

propa-1,2-diene
(*1,2-propadiene*)
Cumulated diene

(2) $CH_2=CH-CH_2-CH=CH_2$

penta-1,4-diene
(*1,4-pentadiene*)
Isolated diene

(3) $CH_2=C(CH_2-CH_3)-C=CH-CH_3$

2-ethylpenta-1,3-diene
(*2-ethyl-1,3-pentadiene*)
Conjugated diene

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States

The first three alkenes, C_2 - C_4 , are gasses at room temperature and normal pressure. C_5 - C_{15} alkenes are liquids and alkenes with 16 and more C-atoms are solids.

Solubility

Alkenes are nonpolar and insoluble in water, but is soluble in many organic solvents. Just like alkanes, alkenes have a density of 0,6 tot 0,7 $g \cdot dm^{-3}$. Because alkenes are less dense and insoluble in water, a mixture of an alkene and water will form two layers, with the alkene the less dense top layer. Therefore alkenes are hydrophobic (water repellent).

Uses

- Lower alkenes are used as fuels.
- Alkenes are utterly important in the synthesis of plastics, by the manufacturing/synthesis of a wide range of polymers, e.g. polythene, polyvinyl chloride (PVC) and Teflon.
- It is used as raw material in the manufacturing of industrial chemicals such as alcohols and amides.
- It is also used in the artificial ripening of fruit and the timely blossoming of flowers. When fruit ripens, certain enzymes in the fruit excrete ethene gas. Ethene (also known as ethylene) is responsible for the colour change, the softening and the sweetness of fruit in the ripening process. Food chemists have learnt that they can suppress ethene production in fruit and thus delay ripening, by storing fruit at low temperatures. If fruit is then dispatched, it is transported at low temperatures, and at the final destination ethene gas is pumped into the containers to accelerate the ripening process again.





Ethene gas (ethylene gas) is used for the ripening of fruit and the timely blossoming of flowers.

Example 3 ALKENES

1. 1.1 What is an alkene? _____

   _____

   1.2 Give the general formula for alkenes. _____

2. The following figure shows the molecular model of eleven alkenes. Give the name, structural formula, condensed formula and molecular formula for each of these alkenes.

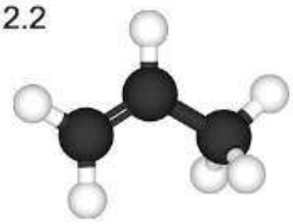
2.1



Name | Structural formula | Condensed formula

Molecular formula

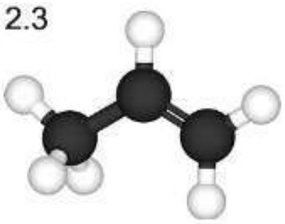
2.2



Name | Structural formula | Condensed formula

Molecular formula

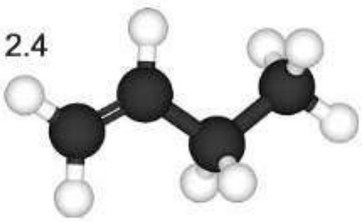
2.3



Name | Structural formula | Condensed formula

Molecular formula

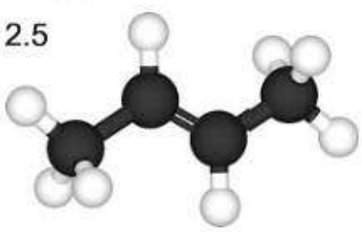
2.4



Name | Structural formula | Condensed formula

Molecular formula

2.5

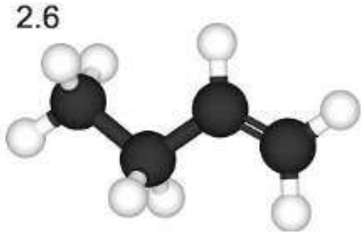


Name | Structural formula | Condensed formula

Molecular formula

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2.6



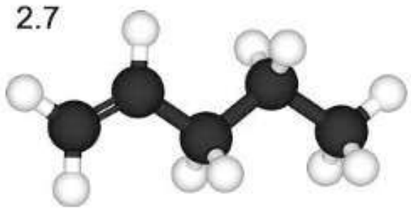
Name

Structural formula

Condensed formula

Molecular formula

2.7



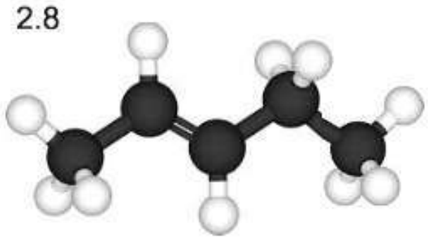
Name

Structural formula

Condensed formula

Molecular formula

2.8



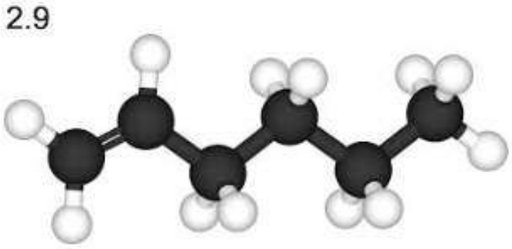
Name

Structural formula

Condensed formula

Molecular formula

2.9



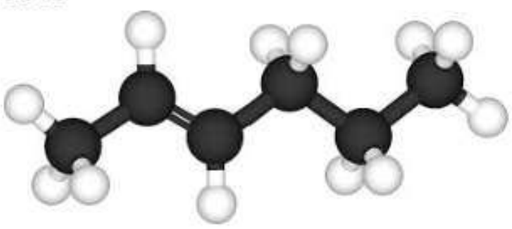
Name

Structural formula

Condensed formula

Molecular formula

2.10



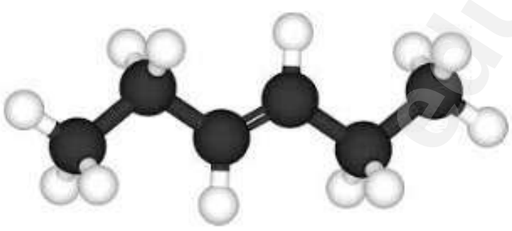
Name

Structural formula

Condensed formula

Molecular formula

2.11



Name

Structural formula

Condensed formula

Molecular formula

3. Give the name of each of the alkenes with the following molecular formula which contains a double bond between carbon C_1 and C_2.

3.1 C_3H_6 _____ 3.2 C_5H_{10} _____

4. Write down the molecular formula for the following alkenes.

4.1 ethene : _____ 4.2 2-hexene : _____ 4.3 3-heptene : _____

5. Draw the structural formula for each of the following alkenes and give the IUPAC-name of each.

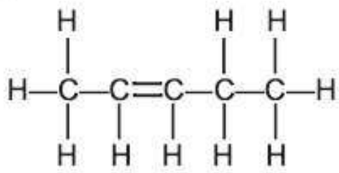
5.1 CH_3CHCH_2 5.2 CH_2CH_2 5.3 $CH_2C(CH_3)CH_3$

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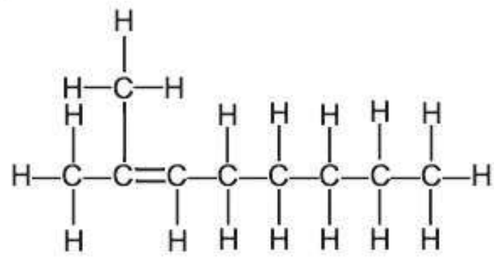
5.4 $CH_3CHCHCH_3$ 5.5 $CH_2CCHCHCH_2CH_3$ 5.6 $CH_3CH_2C(CH_3)CHCH_2$

6. Give the IUPAC names of the alkenes:

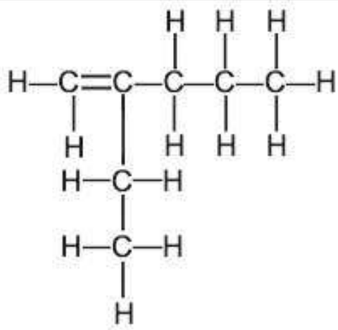
6.1



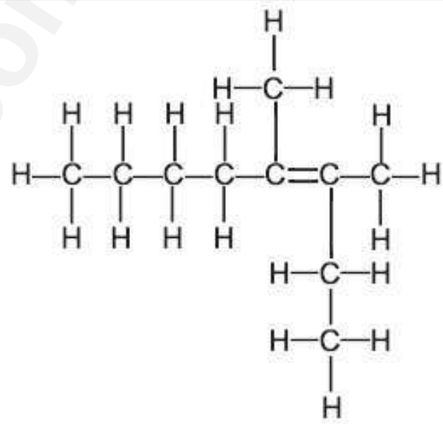
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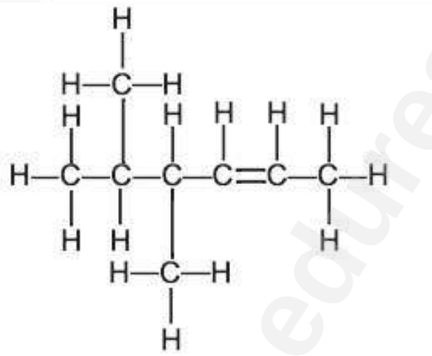
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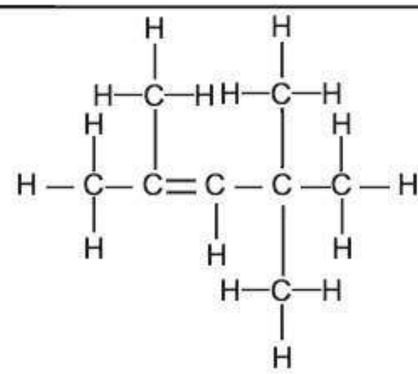
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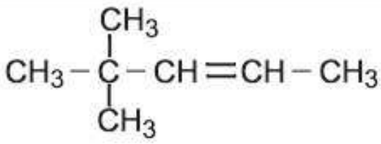
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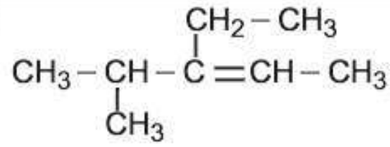
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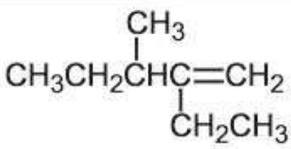
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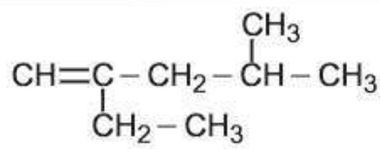
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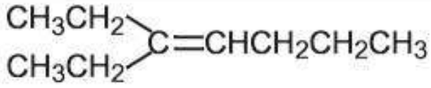
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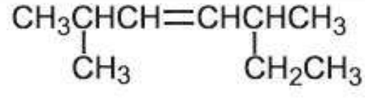
6.10



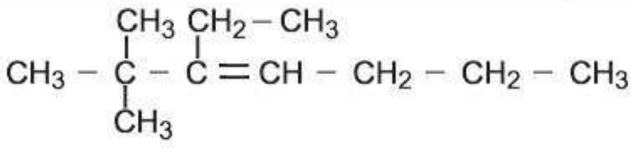
6.11



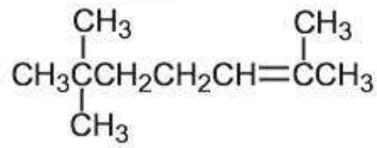
6.12



6.13



6.14



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7. Give the IUPAC names for each of the following alkenes:

7.1 $(CH_3)_2C{=}CH_2$

_____

7.2 $(CH_3)_2CHCH{=}CH_2$

_____

7.3 $CH_3CH{=}C(CH_3)_2$

_____

7.4 $CH_2{=}CH(CH_2)_5CH_3$

_____

7.5 $(CH_3)_3CCH{=}CHCH_3$

_____

7.6 $(CH_3CH_2)_2CHCH{=}CH_2$

_____

8. Draw the structural formula for each of the following alkenes:

8.1 2-methylpent-1-ene

8.2 2,4-dimethylpent-1-ene

8.3 4-ethyl-3-methylhex-2-ene

8.4 3-ethyl-2,2-dimethylhex-3-ene

8.5 2,6,6-trimethylhept-2-ene

8.6 4-ethyl-2,5-dimethylhept-3-ene

9. Draw the conjugated structural formula for each of the following alkenes:

9.1 2,3-dimethylhept-3-ene

9.2 3-ethyl-2,2-dimethylhept-3-ene

9.3 3-ethyl-4-methyloct-4-ene

9.4 2,5,5-trimethylhex-2-ene

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10. Molecules with the general formula C_4H_8 have five isomers of which **three** are **alkenes** and two are cycloalkanes. Draw the structural formulae for the three alkenes. Also give each alkene its IUPAC name.

11. Molecules with the general formula C_5H_{10} have ten isomers of which **five are alkenes** and five are cycloalkanes. Draw the structural formulae of the five alkenes. Also give each alkene its IUPAC name.

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13. Distinguish between conjugated, isolated or cumulated dienes and give an example of each.

14. Class the following dienes as conjugated, isolated or cumulated.

14.1 $CH_2=CH-CH_2-CH=CH_2$

14.2 $CH_2=CH-CH_2-\underset{\displaystyle CH_2-CH_3}{\underset{|}{CH}}-CH=CH_2$

14.3 $CH_2=C=CH_2$

14.4 $CH_3-\underset{\displaystyle CH_3}{\underset{|}{C}}=C=CH-CH_3$

14.5 $CH_2=CH-CH=CH_2$

14.6 $CH_3=\underset{\displaystyle CH_3}{\underset{|}{C}}-CH=CH-CH_3$

15. Give the IUPAC names for each of the following alkenes:

15.1 $CH_3-CH=C=CH_2$

15.2 $H_2C=CHCH_2CH_2CH=CHCH_3$

15.3 $H_2C=CHCH_2CH_2\underset{\displaystyle CH_3}{\underset{|}{C}}=CH_2$

15.4 $CH_2=C=CHCH_3$

15.5 $CH_2=C=\underset{\displaystyle CH_3}{\underset{|}{C}}CH_3$

15.6 $CH_3CH=CHCH=CH_2$

15.7 $CH_3CH_2CH=CHCH_2CH_2CH=CH_2$

15.8 $CH_3\underset{\displaystyle CH_3}{\underset{|}{C}}=CHCH=CH_2$

15.9 $CH_2=CHCH_2CH=\underset{\displaystyle CH_2CH_3}{\underset{|}{C}}CH_2CH_3$

15.10 $CH_3\underset{\displaystyle CH_3}{\underset{|}{C}}=CH\underset{\displaystyle CH_2CH_3}{\underset{|}{C}}HCH_2CH=CH_2$

16. Draw the structural formula for each of the following alkenes:

16.1 3-methylpenta-1-4-diene

16.2 2-methylbuta-1,3-diene

16.3 propa-1,2-diene

16.4 3,5-dimethylhexa-1,4-diene

16.4 5-ethyl-3-methylocta-1,5-diene

16.6 4-elthylhexa-2,4-diene

17. Draw the condensed structural formula for each of the following alkenes:

17.1 3,3-diethylhepta-1,5-diene

17.2 penta-2,3-diene

17.3 5-ethyl-2,3-dimethylocta-2,5-diene

17.4 3,3-dimthylhepta-1,4-diene

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3. ALKYNES - as unsaturated hydrocarbons

The **alkynes** are **unsaturated hydrocarbons** with **triple covalent bonds between C-atoms**. The functional group of alkynes are the carbon-carbon triple bonds and the names end with **– yne**.
In each alkyne there is at least one carbon-carbon triple bond present. The alkynes form a **homologous series** (family of organic compounds) with the general formula C_nH_{2n-2}, where "**n**" is an integer and represents the number of C-atoms in the hydrocarbon, e.g. C_4H_6, C_5H_8 and C_6H_{10}.

• Structure of the alkynes

1. The **first member** of the **alkynes** (or the simplest member of the alkynes) is ethyne. There is no alkyne with only one carbon, as all alkenes need at least two carbons to form the —C≡C— triple bond.

A **model** of the **ethyne molecule** is:



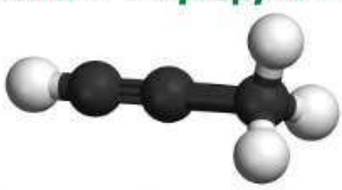
with **molecular formula**: C_2H_2

with **structural formula**: H—C≡C—H

and **condensed structural formula**: HC≡HC

2. The **second member** of the **alkynes** is **propyne**.

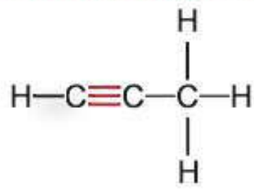
A **model** of the **propyne molecule** is:



with **molecular formula**: C_3H_4

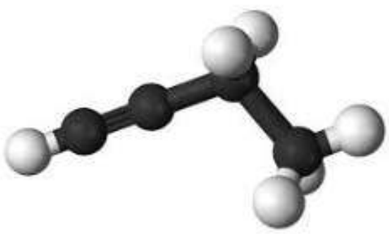
and **condensed structural formula**: $CHCCH_3$ *or* $CH{\equiv}C-CH_3$

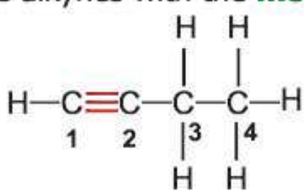
with **structural formula**:



3. **Alkynes** with **four and more C-atoms** form **structural isomers**.

For example the isomers of the alkynes with the **molecular formula C_4H_6**, are:

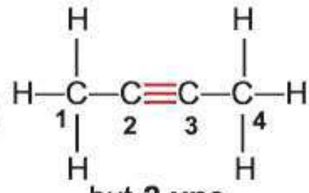




but-**1**-yne

$CH{\equiv}C-CH_2-CH_3$





but-**2**-yne

$CH_3-C{\equiv}C-CH_3$

These two structural isomers are **positional isomers**, which are compounds with the same molecular formula and the same carbon parent chain, but the functional group (triple bond) is situated at different positions on the parent carbon chain.

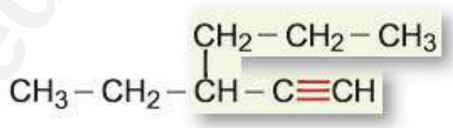
• Naming of alkynes

1. ***Find the longest continuous parent/stem chain which contains the triple bond***

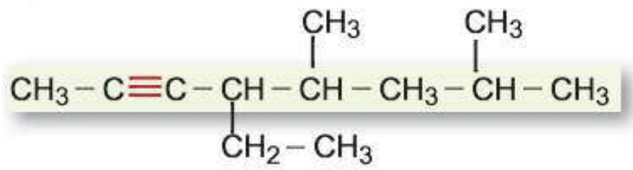
The longest continuous parent/stem chain which contains the triple bond is chosen and the stem name are formed by replacing the suffix "**–ane**" used for alkanes with "**-yne**" for the alkynes. Thus eth**ane** becomes eth**yne**. As two C-atoms are needed to form an alkyne, there is no corresponding compound for methane.



4 C-atoms in longest chain
but**ane** ·····→ but**yn**



6 C-atoms in longest chain
hex**ane** ·····→ hex**yne**



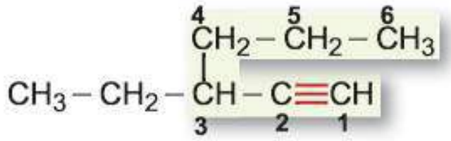
8 C-atoms in longest chain
oct**ane** ·····→ oct**yne**

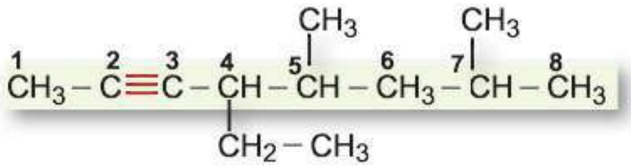
The parent chain must contain the triple bond!

2. ***Number the C-atoms in the parent chain from the side nearest to the triple bond***

The position of the triple bond determines the numbering of the parent chain. For alkynes the triple bond must have the smallest possible number.

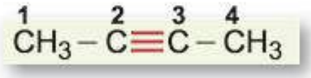


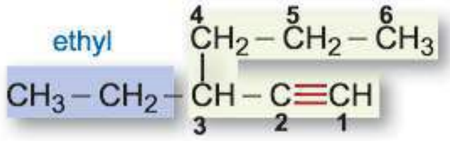


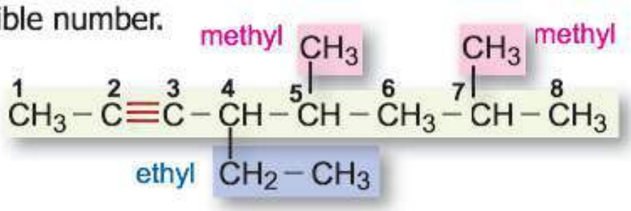


3. ***Identify and number the substituents***

Positions of the alkyl substituents are indicated by numbers as for the alkanes. The double bond however enjoys preference in numbering of the parent chain and the alkyl groups may not necessarily have the lowest numbers. In numbering alkynes, the triple bond must have the lowest possible number.



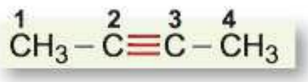




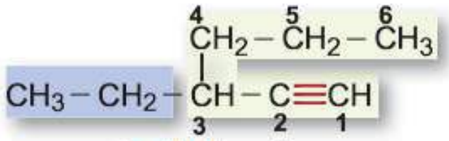
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4. ***Write down the full IUPAC name***

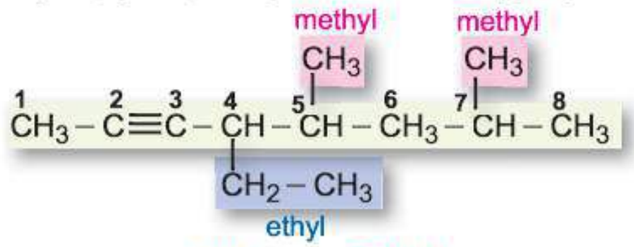
Number the substituents according to their position on the parent chain and list them alphabetically. Indicate the position of the triple bond with a number between the stem name (but-, pent-, hex-) and the suffix (-yne).



but-2-**yne**
(*or 2-butyne*)



3-ethylhex-1-**yne**
(*or 3-ethyl-1-hexyne*)

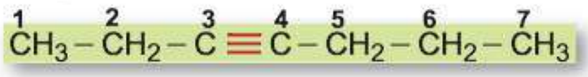


4-ethyl-5,7-dimethyloct-2-**tyne**
(*or (4-ethyl-5,7-dimethyl-2-octyne*)

The position of the triple bond could also be indicated as follows: Instead of **but**-1-**yne** can also be written, 1-**butyne**.

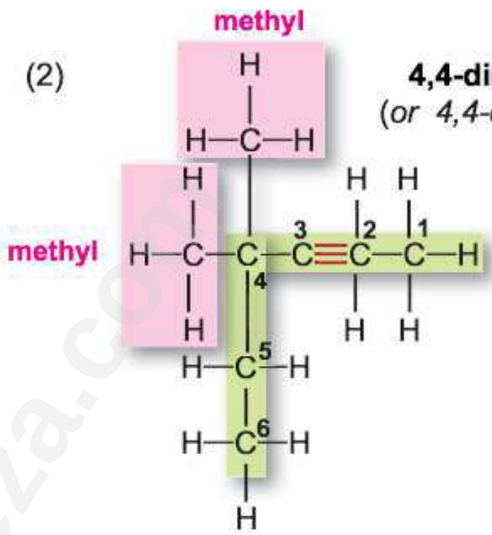
• Example

(1)



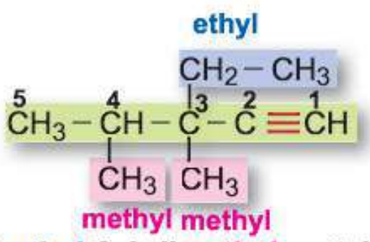
hept-3-yne
(*or 3-heptyne*)

(2)



4,4-dimethylhex-2-yne
(*or 4,4-dimethyl-2-hexyne*)

(3)



3-ethyl-3,4-dimethylpent-1-yne
(*or 3-ethyl-3,4-dimethyl-1-pentyn*)

States

The first three alkynes, C_2 - C_4 are gasses at room temperature and normal pressure. C_5 - C_{17} alkynes are liquids and alkynes with 18 and more C-atoms are solids.

Solubility

Alkynes are nonpolar and insoluble in water but is soluble in many organic solvents. Just like alkanes and alkenes, alkynes have densities lower than that of water. Because the alkynes are less dense and insoluble in water a mixture of an alkyne and water will form two layers, with the alkyne the less dense top layer.

Uses

Acetylene is the industrial name of the organic compound ethyne. The most common use of ethyne (acetylene) is in the oxy acetylene blow torch flame for cutting and welding of metals. Ethyne combust in oxygen and produces an intensely hot flame which can reach temperatures of up to 3000 °C.



Ethyne is used with oxygen in the oxy acetylene flame, which cuts through metals.

Ethyne can be prepared from the reaction of calcium carbide and water:

$$CaC_2(s) + 2H_2O(\ell) \rightarrow C_2H_2(g) + Ca(OH)_2(aq)$$

Acetylene gas lamps were previously used to illuminate buildings, as light beacons in lighthouses and as lights in cars and bicycles. Portable acetylene lamps were also used in mines as lighting in the early twentieth century. Water was dripped onto the calcium carbide which produces acetylene gas which was then ignited to provide light. The production of acetylene was controlled by dripping less or more water onto the calcium carbide. These lamps were usable, but a great risk in coal mines considering the combustibility of methane gas present underground in coal mines.



An acetylene gas lamp

Exercise 4 ALKYNES

1. 1.1 What is an **alkyne**?

_____

1.2 Give the general formula for the alkynes. _____

2. The following figure shows the molecular model of six alkynes. Give the name, structural formula, condensed formula and molecular formula for each of these alkynes.

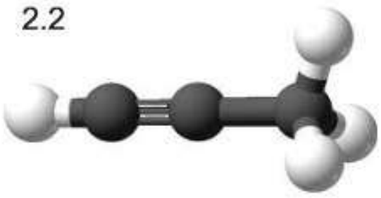
2.1 

Name

Structural formula

Condensed formula

Molecular formula

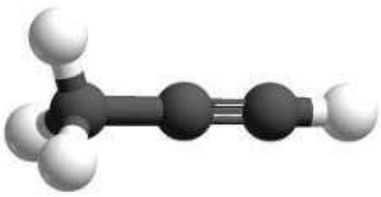
2.2 

Name

Structural formula

Condensed formula

Molecular formula

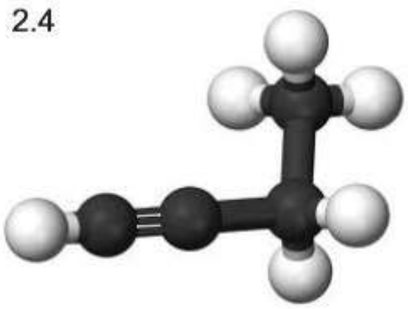
2.3 

Name

Structural formula

Condensed formula

Molecular formula

2.4 

Name

Structural formula

Condensed formula

Molecular formula

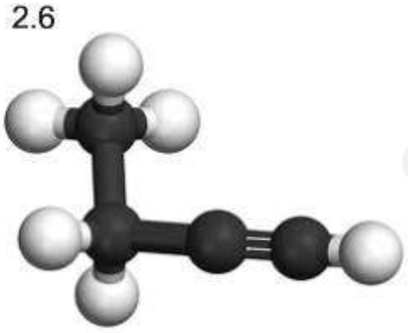
2.5 

Name

Structural formula

Condensed formula

Molecular formula

2.6 

Name

Structural formula

Condensed formula

Molecular formula

3. 3.1 Give the names for the alkynes with the following molecular formula containing a triple bond between C_1 and C_2.

3.1.1 C_3H_4 _____ 3.1.2 C_8H_{14} _____

3.2 Write down the molecular formulae for each of the following alkynes:

3.2.1 ethyne : _____ 3.2.2 hexyne : _____ 3.2.3 heptyne : _____

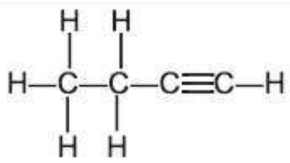
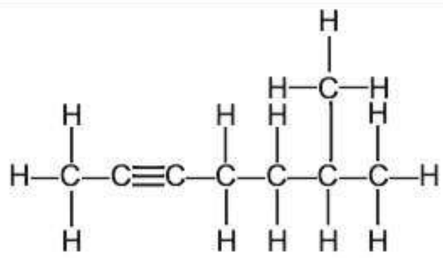
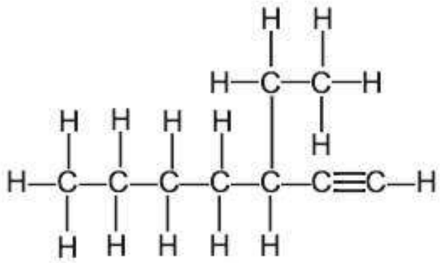
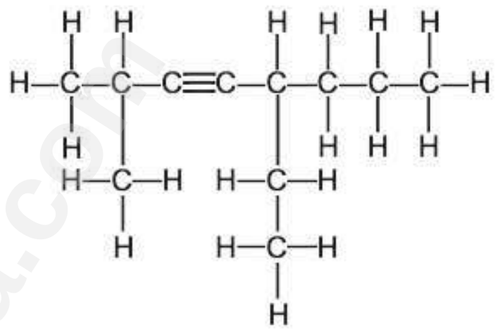
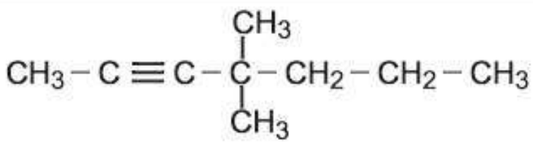
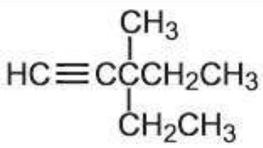
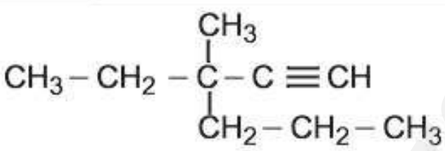
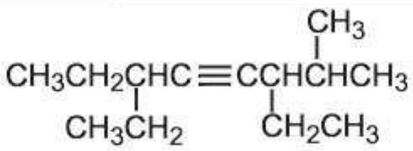
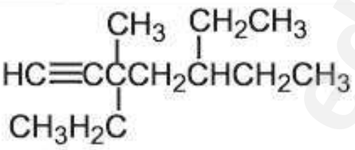
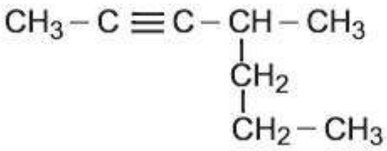
4. Draw the structural formula for each of the following compounds. Also give their IUPAC-names.

4.1 CH_3CCH 4.2 $CH_3CH_2CCCH_2CH_2CH_3$

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4.3 $CH_3CH(CH_3)CCCH_2CH_3$ 4.4 $HCCC(CH_3)_2CH_3$

5. Give the IUPAC names of the following alkynes:

5.1 	5.2 
5.3 	5.4 
5.5 	5.6 
5.7 	5.8 
5.9 	5.10 

6. Draw the structural formula for all alkynes (two) with molecular formula C_4H_6. Also give their IUPAC-names.

7. Draw the structural formula for all alkynes (three) with molecular formula C_5H_8. Also give their IUPAC-names.

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8. Draw the condensed formula for all alkynes (seven) with molecular formula C_6H_{10}. Also give their IUPAC-names.

9. Draw the structural formula for the following alkynes:

9.1 but-2-yne

9.2 4-methylhex-2-yne

9.3 4,4-dimethylpent-2-yne

9.4 3-ethyl-3-methylpent-1-yne

10. Draw the condensed structural formula for the following alkynes:

10.1 hex-3-yne

10.2 3,3-dimethylbut-1-yne

10.3 5,5-dimethylhept-3-yne

10.4 5-ethyl-2,5-dimethyloct-3-yne

10.5 3-ethyl-3-methylhex-1-yne

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4. HALOALKANES (alkyl halides)

Haloalkanes contain one or more than one halogen atom (F, Cℓ, Br or I) that are bonded to saturated C-atoms and have the general formula $C_nH_{2n+1}X$ (**X** = F, Cℓ, Br and I). Haloalkanes are also known as **alkyl halides.** Naming is done similar to the naming of alkyl substituted alkanes.

• Naming of haloalkanes

1. Determine the longest carbon chain (parent chain) and name it as the stem/parent chain. If a double or triple bond is present, it must be part of the parent chain.
2. Number from the side nearest to the first substituent, irrespective of it being a halogen or an alkyl group, if a double or triple bond is present, they enjoy preference above substituents. (when haloalkanes are named the halogen atom is regarded the same as any other substituent, and does not enjoy preference above the others).
3. When more of the same halogen atoms are present, each is awarded the number to which C-atom it is bonded and prefixes di-, tri, tetra, etc. is used to indicate the number of halogen atoms present.
4. If different halogens are present as substituents, they are awarded a number and arranged alphabetically.
5. If different haloalkanes are attached to the same number C-atom irrespective from which side it is numbered, the alphabet prevails (eg. if Br and Cℓ would fall on the same number, Br would get alphabetical precedence)
6. If numbering of the main chain yields the same lowest number when numbering from either side, the side where the substituent has alphabetical precedence would be used.

The naming of the halogen substituent will depend on which halogen is present. The following table list the possible halogen substituents and their naming:

Halogen atom	Name of substituent	Also accepted
F	fluoro-	fluorine-
Cℓ	chloro-	chlorine-
Br	bromo-	bromine-
I	iodo-	iodine-

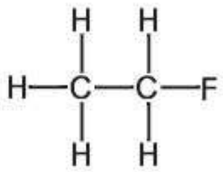
A substituent is an atom or a group of atoms which are bonded to a carbon parent chain. It could be an inorganic atom (i.e halogen) or an alkyl group shorter than the parent chain.

When IUPAC names are written, substituents are written alphabetically, (bromo, chloro, ethyl-, methyl-, ect.) irrespective of the prefixes di-, tri-, tetra-, etc.

• Example

(1) **C_2H_5F**

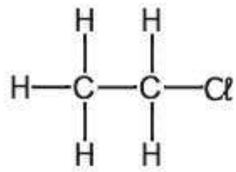




fluoroethane
(*or fluorine ethane*)
CH_3CH_2F

(2) **$C_2H_5C\ell$**

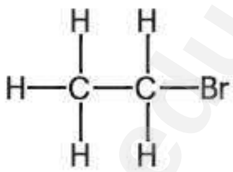




chloroethane
(*or chlorine ethane*)
$CH_3CH_2C\ell$

(3) **C_2C_5Br**

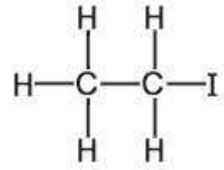




bromoethane
(*or bromine ethane*)
CH_3CH_2Br

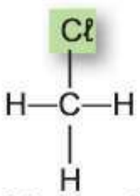
(4) **C_2H_5I**





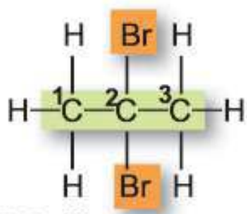
iodoethane
(*or iodine ethane*)
CH_3CH_2I

(5)



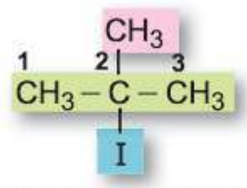
chloromethane
(*or chlorinemethane*)

(6)



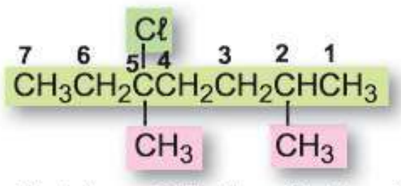
2,2-dibromopropane
(*or 2-dibromonepropane*)

(7)



2-iodo-2-methylpropane
(*or 2-iodine-2-methylpropane*)

(8)



5-chloro-2,5-dimethylheptane
(*or 5-chlorine-2,5-dimethylheptane*)

(9) $CH_2{=}CHC\ell$

chloroethene
(*or chlorineetene*)

(10) $CH_2{=}CHCH_2Br$

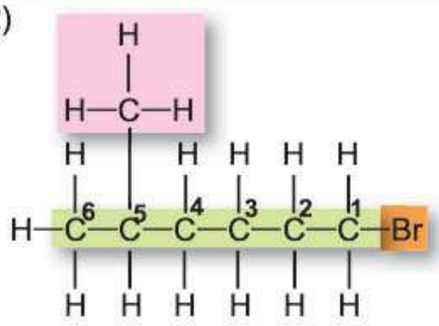
3-bromoprop-1-een
(*of 3-broom-1-propeen*)

(11) $CH{\equiv}CCH_2Br$

3-bromoprop-1-yne (*or 3-bromine-1-propyne*)

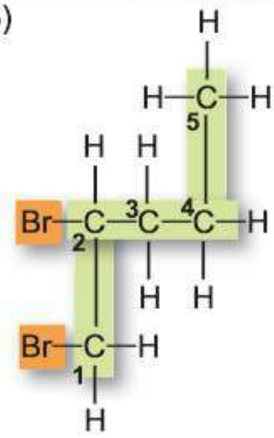
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(12)



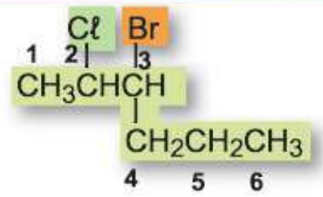
1-bromo-5-methylhexane
(*or 1-bromine-5-methylhexane*)

(13)



1,2-dibromopenthane
(*or 1,2-dibrominepentane*)

(14)

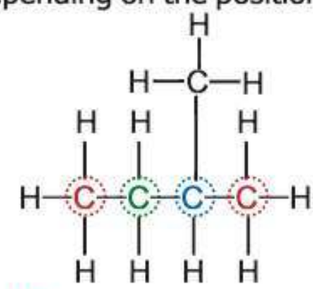


3-bromo-2-chlorohexane
(*or 3-bromine-2-chlorinehexane*)

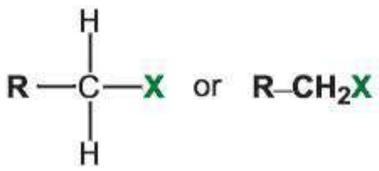
Primary, secondary and tertiary haloalkanes

There are three types of haloalkanes, namely primary, secondary and tertiary haloalkanes, depending on the position of the halogen atom on a primary, secondary or tertiary C-atom.

- A **primary carbon atom** is a carbon which is bound to a maximum of 1 other C-atom (methane's carbon is also a primary C-atom).
- A **secondary carbon atom** is a carbon which is bound to two other C-atoms.
- A **tertiary carbon atom** is a C-atom bound to THREE other C-atoms.

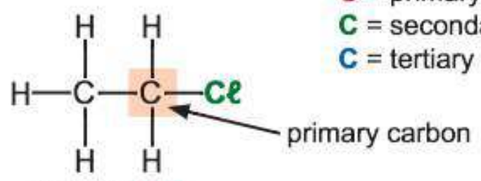


(1) In a **primary haloalkane** the halogen atom **X** (where **X** = F, Cℓ, Br or I) is bound to a primary C-atom, i.e. the halogen atom **X** is bonded covalently to a C-atom that is covalently bonded to a maximum of one other C-atom.



primary haloalkane

example

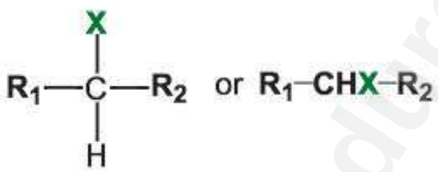


$CH_3CH_2C\ell$

chloroethane
(*or chlorine ethane*)

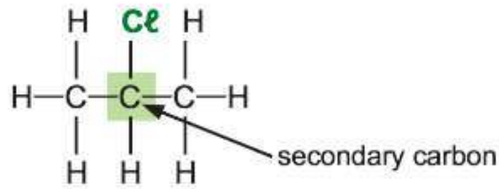
R = H or alkyl group and **X** = F, Cℓ, Br of I

(2) In a **secondary haloalkane** the halogen atom **X** (where **X** = F, Cℓ, Br or I) is bound to a secondary C-atom, i.e. the halogen atom **X** is bonded covalently to carbon that is covalently bonded to two other C-atoms.



secondary haloalkane

example

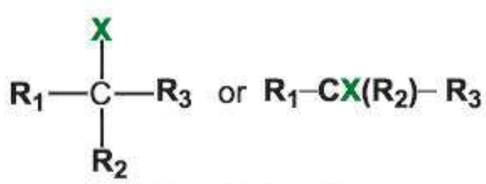


$CH_3CHC\ell CH_3$

2-chloropropane
(*or 2-chlorinepropane*)

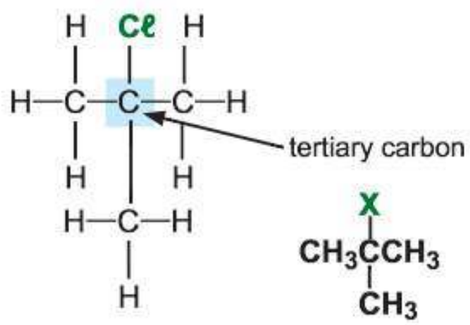
R_1 and **R_2** are alkyl groups and **X** = F, Cℓ, Br or I

(3) In a **tertiary haloalkane** the halogen atom **X** (where **X** = F, Cℓ, Br or I) is bound to a tertiary C-atom, i.e. the halogen atom **X** is bonded covalently to carbon that is covalently bonded to three other C-atoms.



tertiary haloalkane

example



2-chloro-2-methylpropane
(*or 2-chlorine-2-methylpropane*)

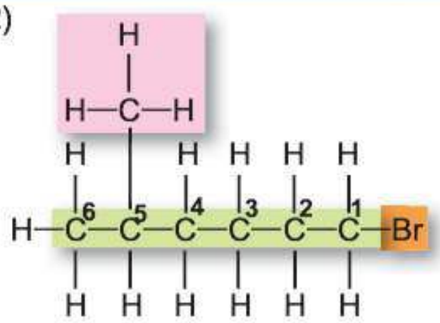
R_1, **R_2** and **R_3** are alkyl groups and **X** = F, Cℓ, Br or I

States

Chloromethane, chloroethane and bromoethane are colourless gasses at room temperature. The other lower molecular mass haloalkynes up to C_{18} are colourless liquids with a sweet (pleasant) smell. Due to photochemical decomposition bromo-and iodo-alkanes alkanes gradually become yellow, and in the case of iodo-alkanes even dark brown.

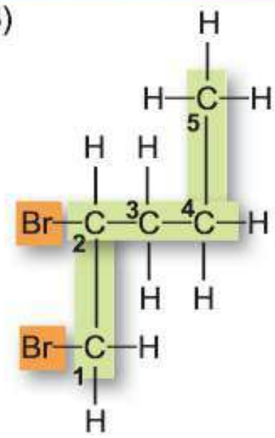
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(12)



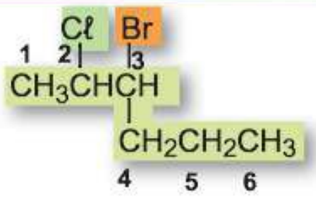
1-bromo-5-methylhexane
(*or 1-bromine-5-methylhexane*)

(13)



1,2-dibromopenthane
(*or 1,2-dibrominepentane*)

(14)

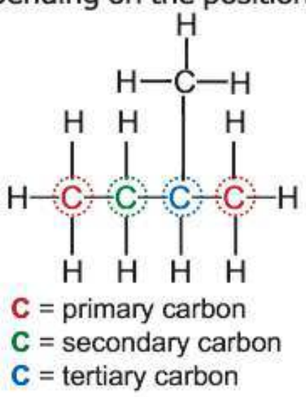


3-bromo-2-chlorohexane
(*or 3-bromine-2-chlorinehexane*)

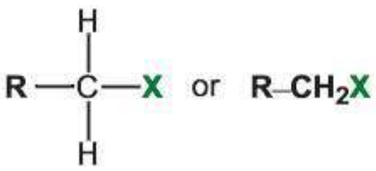
Primary, secondary and tertiary haloalkanes

There are three types of haloalkanes, namely primary, secondary and tertiary haloalkanes, depending on the position of the halogen atom on a primary, secondary or tertiary C-atom.

- A **primary carbon atom** is a carbon which is bound to a maximum of 1 other C-atom (methane's carbon is also a primary C-atom).
- A **secondary carbon atom** is a carbon which is bound to two other C-atoms.
- A **tertiary carbon atom** is a C-atom bound to THREE other C-atoms.

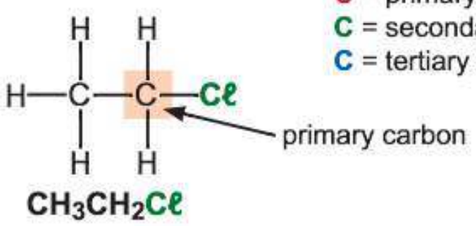


(1) In a **primary haloalkane** the halogen atom **X** (where **X** = F, Cℓ, Br or I) is bound to a primary C-atom, i.e. the halogen atom **X** is bonded covalently to a C-atom that is covalently bonded to a maximum of one other C-atom.



primary haloalkane

example

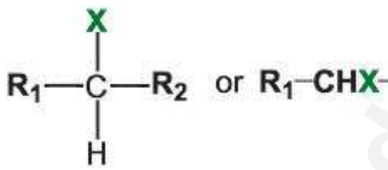


$CH_3CH_2C\ell$

chloroethane
(*or chlorine ethane*)

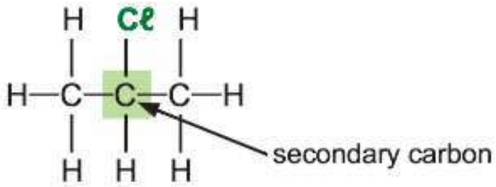
R = H or alkyl group and **X** = F, Cℓ, Br of I

(2) In a **secondary haloalkane** the halogen atom **X** (where **X** = F, Cℓ, Br or I) is bound to a secondary C-atom, i.e. the halogen atom **X** is bonded covalently to carbon that is covalently bonded to two other C-atoms.



secondary haloalkane

example

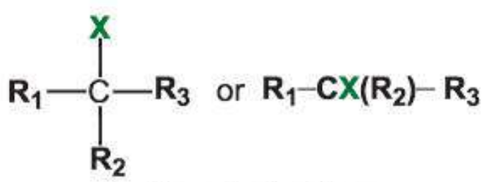


$CH_3CHC\ell CH_3$

2-chloropropane
(*or 2-chlorinepropane*)

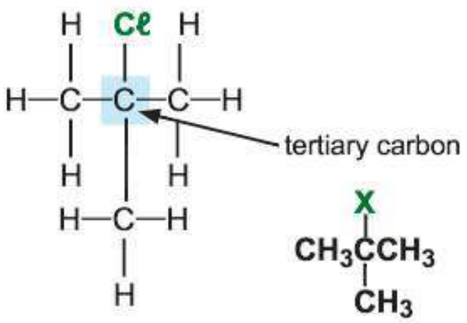
R_1 and **R_2** are alkyl groups and **X** = F, Cℓ, Br or I

(3) In a **tertiary haloalkane** the halogen atom **X** (where **X** = F, Cℓ, Br or I) is bound to a tertiary C-atom, i.e. the halogen atom **X** is bonded covalently to carbon that is covalently bonded to three other C-atoms.



tertiary haloalkane

example



2-chloro-2-methylpropane
(*or 2-chlorine-2-methylpropane*)

R_1, **R_2** and **R_3** are alkyl groups and **X** = F, Cℓ, Br or I

States

Chloromethane, chloroethane and bromoethane are colourless gasses at room temperature. The other lower molecular mass haloalkynes up to C_{18} are colourless liquids with a sweet (pleasant) smell. Due to photochemical decomposition bromo-and iodo-alkanes alkanes gradually become yellow, and in the case of iodo-alkanes even dark brown.

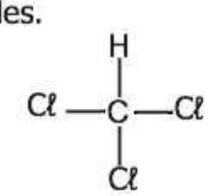
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Solubility

Alkyl halides are nonpolar and therefore insoluble in water, but soluble in organic solvents. Alkyl fluorides and alk chlorides (with only one chlorine atom) are less dense than water and form the top layer in a water solution. Alk chlorides with two or more chlorine atoms are denser than water. All alkyl bromides and alkyl iodides are denser tha water and form the bottom layer in a water solution.

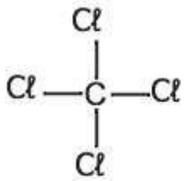
Uses

The alkyl halides (haloalkanes) are important solvents and laboratory reagents. They play an important part medicine as well as in the industry, although some of the original substances have been replaced by less toxic alk halides.



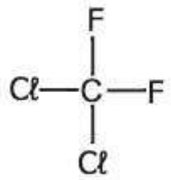
Chloroform (Trichloromethane)





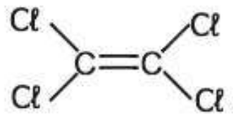
Carbon tetrachloride (Tetrachloromethane)





Dichlorodifluoromethane (CFC)





Tetrachloroethene



- ***Chloroform*** (trichloromethane, **$CHC\ell_3$**) was one of the earliest anaesthetics used in operations. Although th inhalation of chloroform can induce a deep sleep, it is not used as an anaesthetic anymore, due to its toxicity; can cause liver damage - for this reason refrain from inhaling chloroform.
- ***Carbon tetrachloride*** (tetrachloromethane, **$CC\ell_4$**) this substance is non-flammable and has previously bee used as an industrial solvent, a dry cleaning solvent and in fire extinguishers. Due to the fact that it is poisonou and carcinogenic (leads to liver cancer) – it is much less widely used at present.
- ***Dichlorodifluoromethane*** (**CHC's**) were previously widely used as refrigerants, aerosol propellants and foamir agents in polymerization. They are very stable molecules which slowly diffuses to the stratosphere, where sunligl catalyses its decomposition and this contributes to the destruction of the ozone layer (O_3).
- ***Tetrachloroethene*** (**$C_2C\ell_4$**) is widely used in the dry cleaning industry at present instead of **$CC\ell_4$**.

Exercise 5 HALOALKANES

1. 1.1 What is a **haloalkane**?

_____

_____

1.2 What are haloalkanes also known as? _____

1.3 Give the general formula for the haloalkanes. _____

2. Draw the structural formulae and give the IUPAC-names for the structural isomers of:

2.1.1 C_3H_7Br

2.1.2 C_4H_9Br

2.2 Distinguish between a primary, secondary and tertiary haloalkane.

2.3 Classify each of the isomers drawn in Question 2.1.1 and 2.1.2 as a primary, secondary or tertiary haloalkane.

3. Classify each of the following as a primary, secondary or tertiary haloalkane:

3.1 $CH_3C(CH_3)_2Br$ _____ 3.2 $CH_3CH_2CH_2Br$ _____

3.3 $CH_3CH_2C(CH_3)_2Br$ _____ 3.4 $(CH_3CH_2)_2CHC\ell$ _____

3.5 $BrCH_2CH_2CH_2Br$ _____ 3.6 1-fluoropentane _____

3.7 2-fluorobutane _____ 3.8 2-bromo-2-methylpentane _____

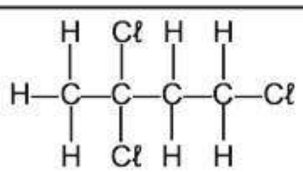
4. Draw the condensed structural formulae and give the IUPAC-names for the eight structural isomers with the molecular formula $C_5H_{11}C\ell$.

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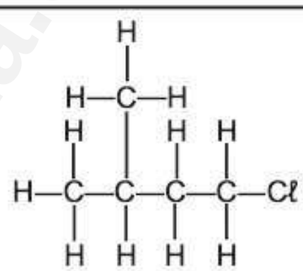
5. Draw the condensed structural formulae and give the IUPAC-names for the nine structural isomers with the molecular formula $C_4H_8Br_2$.

6. Give the IUPAC-names for each of the following halogen compounds:

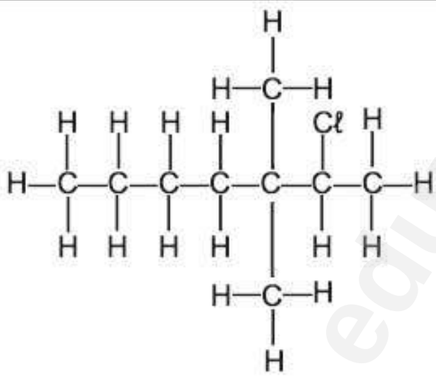
6.1



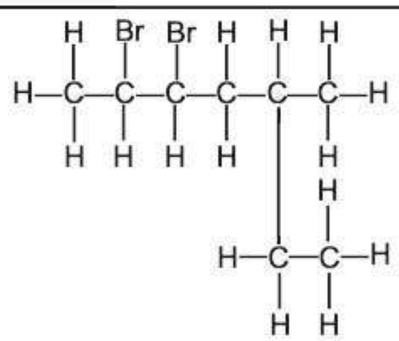
6.2



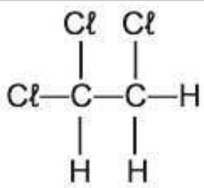
6.3



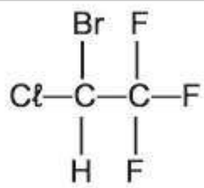
6.4



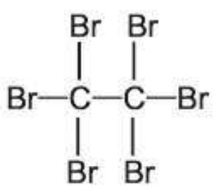
6.5



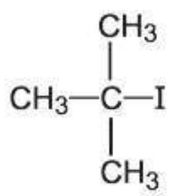
6.6



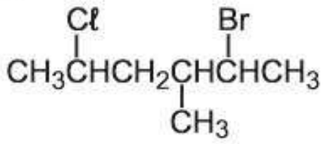
6.7



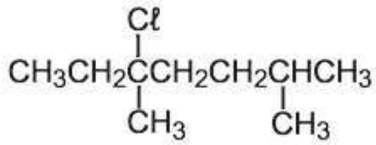
6.8



6.9



6.10



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6.11 $CH \equiv CCH_2C\ell$	6.12 $CH \equiv CC\ell$
6.13 $CH_3CH = CHCH_2\underset{\displaystyle I}{\underset{\vert}{C}}HCH_3$	6.14 $BrCH\underset{\displaystyle C\ell}{\underset{\vert}{C}} \equiv CC\ell$
6.15 $CH_3CH = \underset{\displaystyle Br}{\underset{\vert}{C}}\underset{\displaystyle CH_3}{\underset{\vert}{C}}HCH_3$	6.16 $CH_3\underset{\displaystyle CH_3}{\underset{\vert}{C}}HC \equiv C\underset{\displaystyle Br}{\underset{\vert}{C}}H_2CHCH_3$

7. Draw the structural formulae for the following haloalkanes:

7.1 1,2,2-trichlorobutane

7.2 4-bromo-2-chloro-4-methylhexane

7.3 hexchloroethene

7.4 4,4-difluoro-3-methylbut-1-ene

7.5 1,1-difluoro-3-methyl-buta-1,3-diene

7.6 2-bromo-4-chloropenta-2,3,diene

8. Give the condensed structural formulae of the following haloalkanes:

8.1 3-ethyl-3-iodopenthane

8.2 1-bromobuta-1,2-diene

8.3 2-chloro-3-methylbut-1-ene

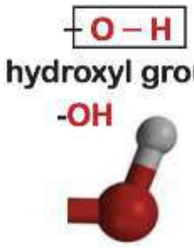
8.4 2-bromo-5-chlorohexa-2,3-diene

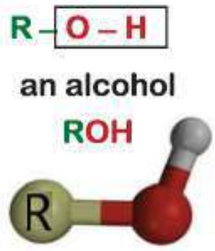
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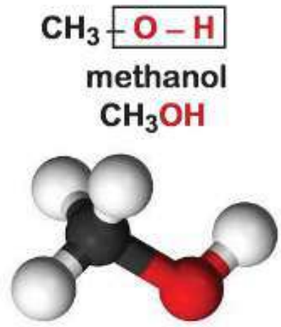
5. ALCOHOLS

Alcohols are the group of organic compounds consisting of polar organic molecules which contains one or more **hydroxyl** (**-OH**) **group**. Alcohols form a homologous series with general formula $C_nH_{2n+1}OH$ and often the notation **ROH** is used to depict an alcohol where **R** = alkyl group.

Alcohol acid functional group







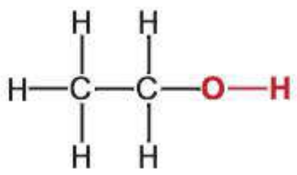
• Naming of alcohols

1. Determine the longest parent chain that contains the **hydroxyl group** (-OH) and determine the stem by counting the number of C-atoms. The name ends with **–ol**, e.g. - methan**ol**.
2. Start numbering on the end nearest to the hydroxyl group to indicate its position in the parent chain.
3. Number the substituents and arrange them alphabetically.
4. If there are **two hydroxyl groups** present, it is called a –diol and the name ends with –diol, e.g. propan-1,3-**diol** (1,3-propandiol).
5. If there are **three hydroxyl groups** present, it is called a –triol and the name ends with –**triol**, e.g. propan 1,2,3-triol (1,2,3-propantriol).

• Examples

(1) C_2H_5OH



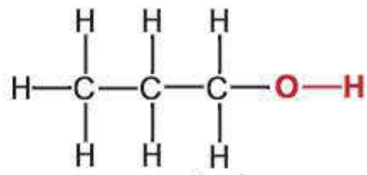


ethanol

CH_3CH_2OH

(2) C_3H_7OH





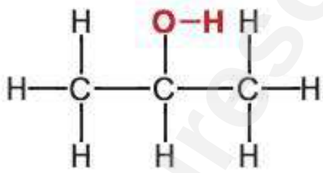
propan-1-ol

(*or 1-propanol*)

$CH_3CH_2CH_2OH$

(3) C_3H_7OH





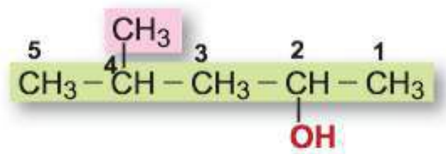
propan-2-ol

(*or 2-propanol*)

$CH_3\underset{OH}{C}HCH_3$

Propan-1-ol (1-propanol) and **propan-2-ol** (2-propanol) are **positional structural isomers**.

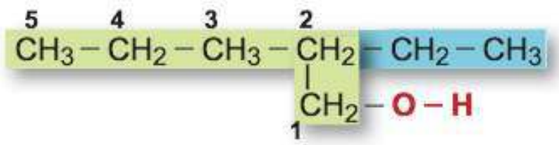
(4)



4-methyl-pentan-2-ol

(*or 4-methyl-2-pentanol*)

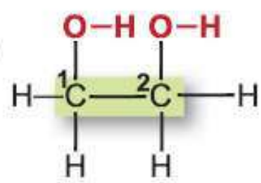
(5)



2-ethyl-butan-1-ol

(*or 2-ethyl-1-butanol*)

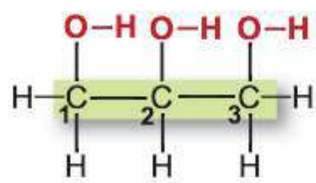
(6)



etan-1,2-diol

(ethylene glycol)

(7)



propan-1,2,3,-triol

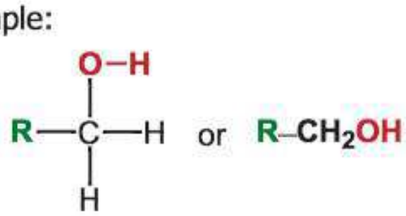
(glycerol)

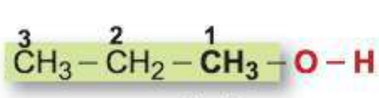
Primary, secondary and tertiary alcohols

• Primary alcohols (-OH group is at the tip of the chain)

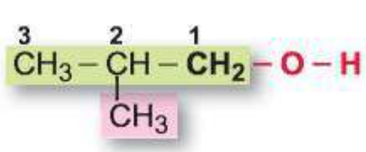
In a **primary alcohol** the **-OH** group is bonded to a primary C-atom. I.e. in a primary alcohol molecule the C-atom that contains the **-OH** group is attached to the tip of the longest chain. There is at the most one alkyl group (R) and two H-atoms bonded to the carbon which contains the **-OH** group.

Example:





propan-1-ol



2-methylpropan-1-ol

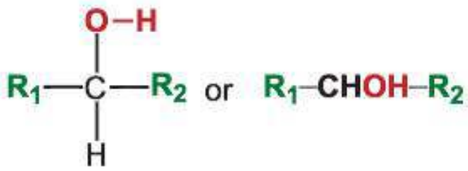
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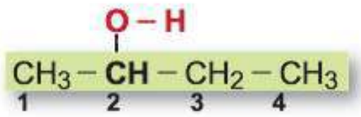
• Secondary alcohols (-OH group is inside the chain)

In a **secondary alcohol** the **-OH** group is attached to a secondary C-atom, i.e. in a secondary alcohol molecule the C-atom that contains the **-OH** group is part of the carbon chain that is directly bonded to two alkyl groups which may or may not be of equal length.

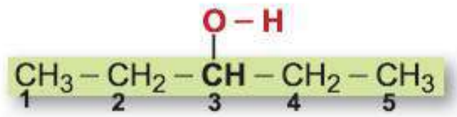
There are two alkyl groups (R_1 and R_2) and one H-atom bonded to the carbon of the C-**OH** group.

For example:





butan-2-ol



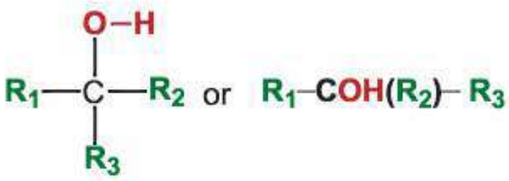
pentan-3-ol

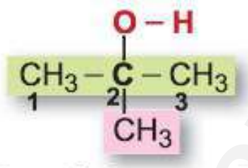
• Tertiary alcohols (needs a branched chain)

In a **tertiary alcohol** the **-OH** group is attached to a tertiary C-atom, i.e. in a tertiary alcohol molecule the C-atom that contains the **-OH** group is part of the carbon chain that is directly bonded to three alkyl groups which may or may not be of equal length.

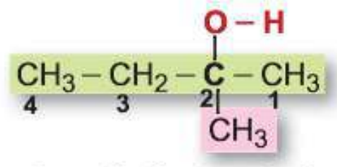
There are three alkyl groups (R_1, R_2 and R_3) and no H-atoms bonded to the C-atom of the C-**OH** group.

Example:





2-methylpropan-2-ol



2-methylbutan-2-ol

States

The lower alcohols are liquids with a characteristic odour, while the higher alcohols are odourless solids.

Solubility

Alcohols that have five and less C-atoms are soluble in water because they have an O-atom available to form a hydrogen bond with water. Alcohols with more than five C-atoms are insoluble in water because the nonpolar alkyl portion is to large to dissolve in water. So, as the alkyl chain in the alcohol increases in length, the solubility of alcohol in water decreases drastically. Alcohols with two and more -OH groups (diols and triols) can form more than one hydrogen bond, therefore they are more water soluble than similar alcohols with one -OH group. Alcohols of any size are soluble in organic solvents.

Uses

Methanol (CH_3OH, methyl alcohol) is an extremely poisonous liquid and can cause permanent blindness. It is used as solvent in many organic processes and sold for use in primus stoves as fuel.

Ethanol (CH_3CH_2OH) is a clear liquid and is also known as ethyl alcohol. It is present in alcoholic drinks such as wine and beer. It is prepared by the enzymatic fermentation of glucose (grape sugar) to ethanol from plants like barley, maize, grapes and sugar cane.

$$\underset{\text{glucose}}{C_6H_{12}O_6} \xrightarrow[\text{yeast}]{\text{enzymes}} \underset{\text{ethanol}}{2C_2H_5OH} + 2CO_2$$





Methanol is used in methylated spirits. Beer contains ethanol.

Ethanol can also be used as fuel in cars. Some cars are designed to use ethanol, rather than petrol. These vehicles are used in countries with excess sugar cane.

Ethan-1,2-diol (user name: ethylene glycol) is used as the main ingredient in anti-freeze which is used in radiators, while propan-1,2,3-triol (user name: glycerol) is used as moisturizers in foods and in cosmetics.

Exercise 6 ALCOHOLS

1. 1.1 What is an **alcohol**?

_____

_____

_____

1.2 Give the functional group for alcohols. _____

1.3 Give the general formula for alcohols. _____

1.4 Which of the following compounds represent a alcohol?

A. $CH_3CH_2CH_2OH$ B. CH_3CH_2CHO C. $CH_3CH_2COCH_3$ D. $CH_3CH_2CH(OH)CH_2CH_3$:_____

2. 2.1 Distinguish between primary, secondary and tertiary alcohols.

_____

_____

_____

_____

_____

_____

_____

_____

_____

2.2 Identify the following alcohols as primary, secondary or tertiary alcohols:

2.2.1 CH_3CH_2OH _____ 2.2.2 $CH_3CH(CH_3)CH_2OH$ _____

2.2.3 $CH_3CH(OH)CH_3$ _____ 2.2.4 $(CH_3)_3COH$ _____

2.2.5 ethanol _____ 2.2.6 pentan-3-ol _____

2.2.7 3-methylbutan-2-ol _____ 2.2.8 methylpentan-1-ol _____

2.2.9 methylpropan-2-ol _____ 2.2.10 3-methylpentan-3-ol _____

3. For each of the following molecular formulae, give the structural formulae for the possible structural isomers for the alcohols with these formulae. Give the IUPAC-name of each alcohol, also state if it's a primary, secondary or tertiary alcohol.

3.1 C_3H_8O (or C_3H_7OH)

3.2 $C_4H_{10}O$ (or C_4H_9OH)

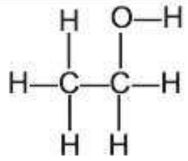
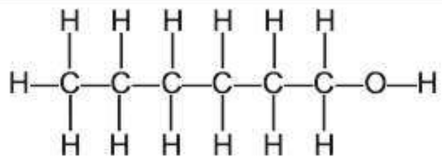
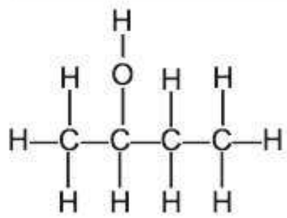
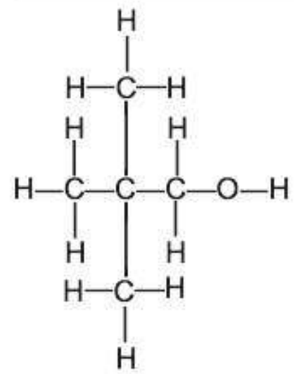
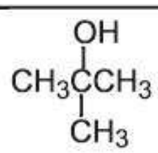
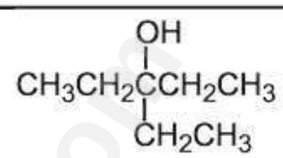
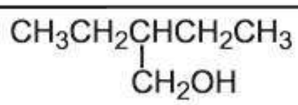
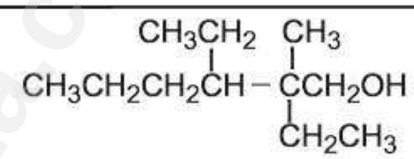
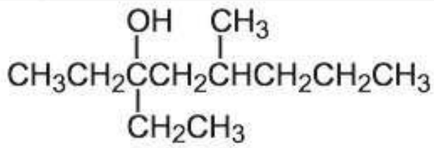
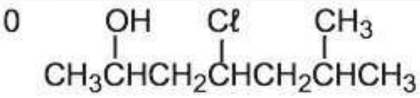
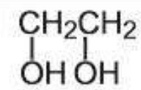
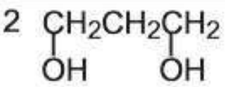
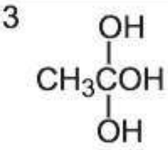
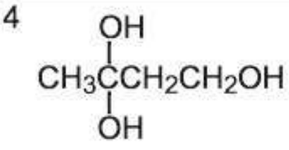
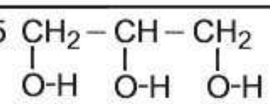
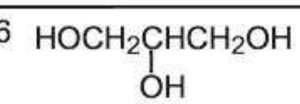
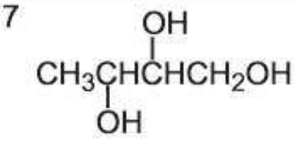
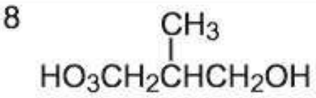
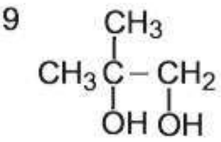
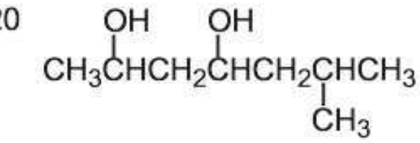
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4. Draw the structural formulae for the **eight alcohol** isomers with the molecular formula $C_5H_{12}O$ (or $C_5H_{11}OH$) and give their IUPAC-names.

5. Draw the condensed structural formulae for the **seventeen** alcohol isomers with molecular formula $C_6H_{14}O$ (or $C_6H_{13}OH$) and give their IUPAC-names.

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6. Give the IUPAC-names for each of the following compounds:

6.1 	6.2 
6.3 	6.4 
6.5 	6.6 
6.7 	6.8 
6.9 	6.10 
6.11 	6.12 
6.13 	6.14 
6.15 	6.16 
6.17 	6.18 
6.19 	6.20 

7. Draw the structural formulae of the following alcohols:

7.1 methanol

7.2 ethanol

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7.3 3-methylpentan-3-ol

7.4 3,3-dichloropentan-1-ol

7.5 3-methylpropan-1,3,-diol

7.6 5-bromo-5-methylhexan-1,3,4-triol

7.7 3-methylbutan-1,2,3-triol

7.8 2-chlorobutan-2,3-diol

8. Draw the condensed structural formulae for the following alcohols:

8.1 2,4-dimethylpentan-2-ol

8.2 5,5-diethylheptan-1-ol

8.3 hexan-1,5,-diol

8.4 5-methylhexan-2,4-diol

8.5 3,3-diethyl-6-methyloctan-2,6-diol

8.6 5-bromo-5-methylhexan-3-ol

8.7 2,2-diethyl-2-methylhexan-1-ol

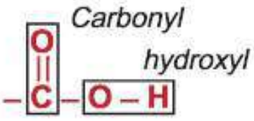
8.8 6-methylpropan-1,2-diol

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6. Carboxylic acids

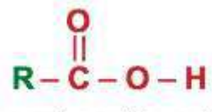
Carboxylic acids are organic compounds where the molecules contain a carboxyl group, **-COOH** [Carboxyl (**-COOH**) = Carbonyl (**-CO-**) + hydroxyl(**-OH**)]. The carboxylic acids form a homologous series with the general formula $C_nH_{2n+1}COOH$ (or $C_nH_{2n}O_2$) and often the notation **ROOH** is used, where **R** is a alkyl group.

Carboxylic acid functional group



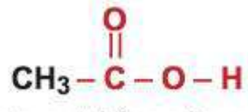
carboxyl group
-COOH





A carboxylic acid
RCOOH of RCO_2H





ethanoic acid (acetic acid)
CH_3COOH

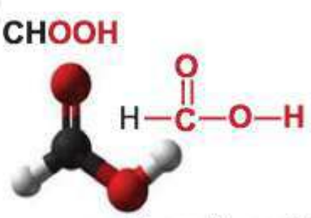


• Naming of carboxylic acids

1. Carboxylic acid names end with **– anoic acid**.
2. The parent chain must contain the carboxyl group (**-COOH**) and numbering starts at the carboxyl group.
3. Number the substituents according to their positions and list them alphabetically in the final name.

• Examples

(1)



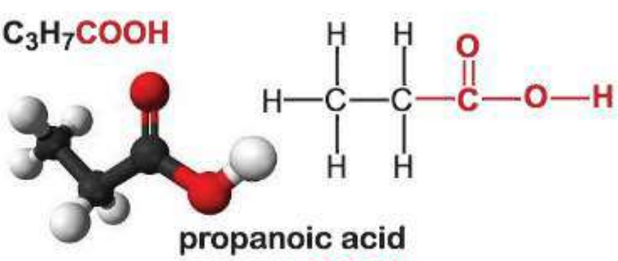
methanoic acid
HCOOH

(2)



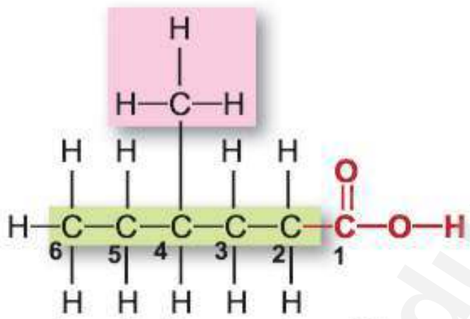
ethanoic acid
CH_3COOH

(3)



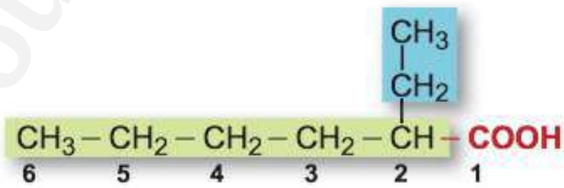
propanoic acid
CH_3CH_2COOH

(4)



4-methylhexanoic acid

(5)



2-ethylhexanoic acid

States

Lower carboxylic acids (up to C10) are liquids with sharp unpleasant odours. Higher groups are waxy solids and mostly odourless.

Solubility

Carboxylic acids with one to four C-atoms are quite soluble in water because the carbonyl group contains two O-atoms that form hydrogen bonds with several water molecules. The higher hydrophilic acids (hydrophobic acids) are less soluble in water, watersolubility dramatically decreases with an increase in the length of the C-chain (nonpolar alkyl group) - they tend to be more soluble in solvents such as ethers and alcohols.

Uses

Methanoic acid (**HCOOH**, formic acid) is found in stinging nettles and in ant venom.
Ethanoic acid (**CH_3COOH**, acetic acid) is the ingredient of vinegar.
Buthanoic acid (**$CH_3CH_2CH_2COOH$**, butyric acid) is found in rancid butter.





Examples where carboxylic acids are found.

- Carboxylic acids consisting of oils and fats, are called fatty acids. Stearic acid, an ingredient in animal fat is used to make soap.
- Organic acids are weak acids and ionise partially in water.

$$\underset{\text{ethanoic acid}}{CH_3COOH(\ell)} + H_2O(\ell) \rightleftharpoons \underset{\text{hydronium ion}}{H_3O^+(aq)} + \underset{\text{ethanoate ion}}{CH_3COO^-(aq)}$$

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Exercise 7 CARBOXYLIC ACID

1. 1.1 What is a **carboxylic acid**?

_____

_____

_____

1.2 Give the general formula for carboxylic acid. _____

1.3 Which of the following represent a carboxylic acid?

A. CH_3-CH_2-CH(CH_3)-COOH
B. $(CH_3)_2$CH-CHO
C. CH_3-CH_2OH
D. C_6H_5-CH_2-COOH Answer: _____

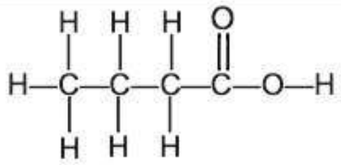
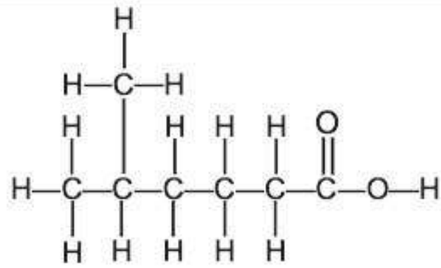
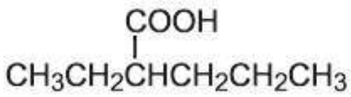
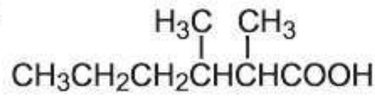
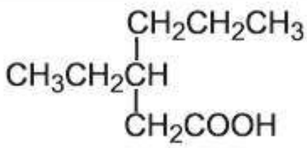
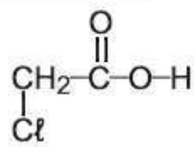
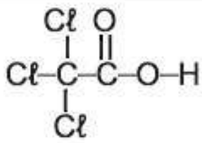
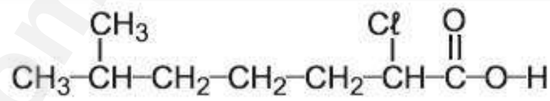
2. Draw the structural formulae and give the IUPAC-names for the **two** structural isomers of carboxylic acid with the molecular formula $C_4H_8O_2$.

3. Draw the structural formulae and give the IUPAC-names for the **four** different carboxylic acids with the molecular formula $C_5H_{10}O_2$.

4. Draw the condensed structural formulae and give the IUPAC-names for the **eight** different carboxylic acids with the molecular formula $C_6H_{12}O_2$.

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5. Give the IUPAC-names for the following **carboxylic acids**:

5.1 	5.2 
5.3 	5.4 
5.5 	5.6 
5.7 	5.8 
5.9 $CH_3(CH_2)_6COOH$	5.10 $(CH_3CH_2)_3COOH$

6. Draw the structural formulae of the following carboxyl acids:

6.1 metanoicacid

6.2 2-methylpentanoicacid

6.3 2-ethylbutanoicacid

6.4 3,4-dimethylpenatnoicacid

6.5 4-bromo-2-methylbutanoicacid

6.6 trifluoroetanoicacid

7. Draw the condensed structural formulae of the following carboxylic acids:

7.1 etanoicacid

7.2 2,3-dimethylbutanoicacid

7.3 4-bromo-4-chlorohexanoicacid

7.4 4-bromo-5,5-dichloro-3-methylpentanoicacid

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7. ESTERS

Esters are derivatives of carboxylic acids and are therefore related to carboxylic acids. They contain a carboxylic group of which the H-atom has been replaced by an alkyl group (**R**). The general formula of esters and the carboxylic acids is the same, namely $C_nH_{2n}O_2$.

The ester functional group



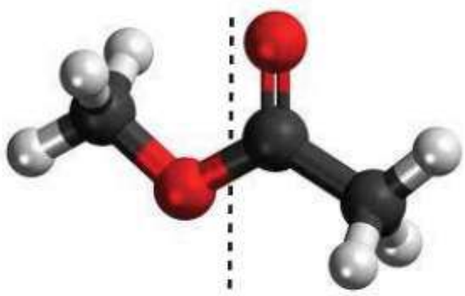
$R_1 - C(=O) - O - R_2$ or $R_1 - COO - R_2$

an Ester

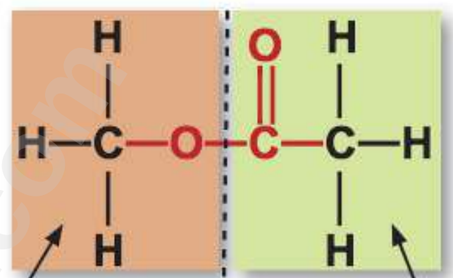
where R_1 = **H** or methyl (**-CH_3**) or ethyl (**-CH_2CH_3**), ect.
and R_2 = **H** or methyl (**-CH_3**) or ethyl (**-CH_2CH_3**), ect.

Esters are formed by the reaction of an alcohol and a carboxylic acid. The name of the ester partly comes from an alcohol and partly from a carboxylic acid.

Methyl Methanoate is prepared by the reaction of methanol and methanoic acid.



Alcohol portion | Carboxylic acid portion



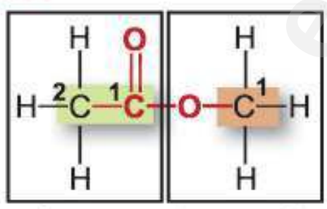
Alcohol portion | Carboxylic acid portion

• Naming of esters

1. Make an imaginary split in the ester between the C-atom of the carbonyl group (**-CO-** or $-C(=O)-$) and the **-O-**atom which is bonded to the (**-CO|O-**) or $-C(=O)-|-O-$
   The carbonyl group of the compound is derived from the carboxylic acid and the part where the **-O-** atom is bonded to an alkyl group, is derived from the alcohol.
2. Firstly name the organic group (alkyl group) attached to the oxygen and which name is derived from the parent alcohol that is present.
   E.g. methan**ol** becomes meth**yl**, ethan**ol** becomes eth**yl**, propan**ol** becomes prop**yl**, etc.
3. Secondly name the acidic part derived from the carboxylic acid, by replacing the suffix **–oic** acid with **-oate**, e.g. methan**oic** acid becomes methan**oate**, ethan**oic** acid become ethan**oate**, propan**oic** acid becomes propan**oate**, etc.
4. Place the alcohol part first and then finally the carboxylic part second, e.g. **methyl ethanoate**.

• Examples

(1)



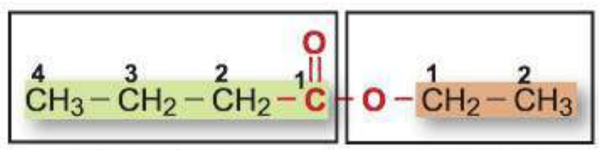
2nd = part from carboxylic acid ethanoic acid = **ethanoate**

1e = part from alcohol methanol = **methyl**

$CH_3CO|OCH_3$

methyl methanoate

(2)



2nd = part from carboxylic acid butanoic acid = **buthanoate**

1nd = part from alcohol ethanol = **ethyl**

$CH_3CH_2CH_2CO|OCH_2CH_3$

ethyl butanoate

States

Esters are colourless, neutral liquids and solids with pleasant odours. This smells (aromas) are often responsible for the smell of fruit and flowers.

Solubility

The smaller esters are readily soluble in water but their solubility drastically decreases with an increase in the length of the C-chain (nonpolar alkyl group). The reason for solubility of esters in water is that easter can not form hydrogen bonds with themselves but, esters can form hydrogen bonds with water molecules.





Esters are largely responsible for the aromas of flowers and perfume.

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Uses

Apart from their use as seasoning and fragrances in the food and cosmetic industry, esters have many other important widespread uses. Which includes:

- formation of fats, oils and soap.
- production of poly-esters such as Terylene.
- Ethyl ethanoate and other lower esters are used as solvents for many paints, varnishes, adhesives and glues.

Exercise 8 ESTERS

1. 1.1 What is an **ester**?

_____

_____

_____

1.2 Give the general formula for esters. _____

2. Complete the following table:

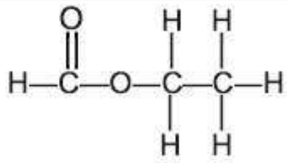
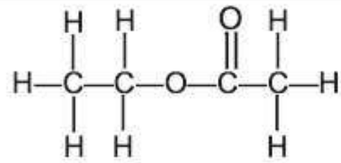
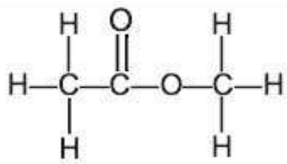
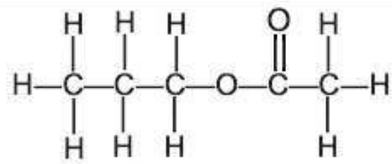
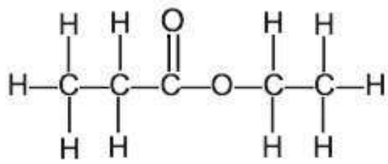
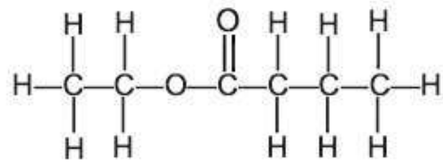
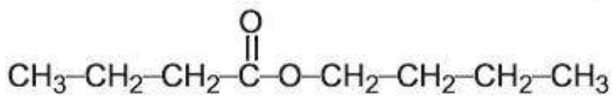
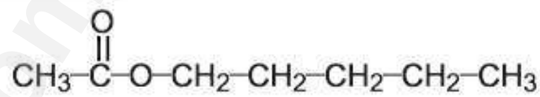
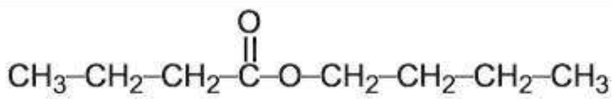
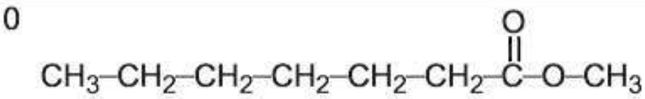
Alcohol	Carboxyl acid	Ester	Molecular formula
methanol	ethanoic acid		
ethanol	methanoic acid		
propanol	methanoic acid		
methanol	propanoic acid		
		prophylenthanoate	
		ethylbutanoate	
		penthylpentanoate	
		buthyloctanoate	

3. Draw the structural formulae and give the IUPAC-names for the **two** unbranched esters with the molecular formula $C_3H_6O_2$.

4. Draw the structural formulae and give the IUPAC-names for the **four** unbranched esters with the molecular formula $C_5H_{10}O_2$.

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5. Give the IUPAC-names of the following esters:

5.1 	5.2 
5.3 	5.4 
5.5 	5.6 
5.7 	5.8 
5.9 	5.10 
5.11 $CH_3COOCH_2CH_2CH_2CH_2CH_2CH_3$	5.12 $HCOOC_7H_{15}$
5.13 $CH_3CH_2CH_2CO_2(CH_2)_4CH_3$	5.14 $CH_3(CH_2)_6CO_2C_2H_5$

6. Draw the structural formulae of the following esters:

6.1 methyl ethanoate

6.2 ethyl hexanoate

6.3 propyl butanoate

6.4 hexyl ethanoate

7. Draw the condensed structural formulae of the following esters:

7.1 methyl octanoate

7.2 ethyl propanoate

7.3 hexyl etanoate

7.4 butyl pentanoate

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8. ALDEHYDES AND KETONES

Aldehydes and ketones are compounds containing a **carbonyl group** () ; an oxygen atom, with the help of a double bond, is bonded to a C-atom in an organic molecule.

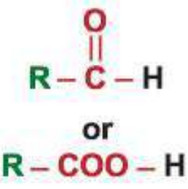
8.1 ALDEHYDES

An **aldehyde** is an organic compound that contains a carbonyl group with at least one H-atom attached to it. The 2nd group could be another H-atom (the simplest aldehyde) or it could be an alkyl group.

The general formula of the aldehydes $C_nH_{2n}O$ is the same as for the ketones.

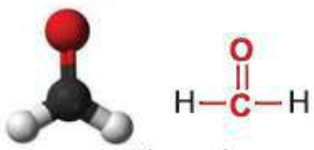
The aldehyde functional group



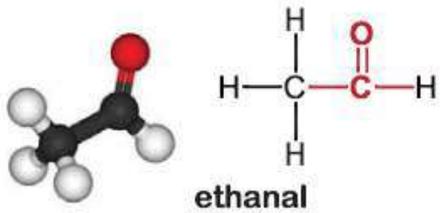


R = H, -CH_3, C_2H_5, ect.

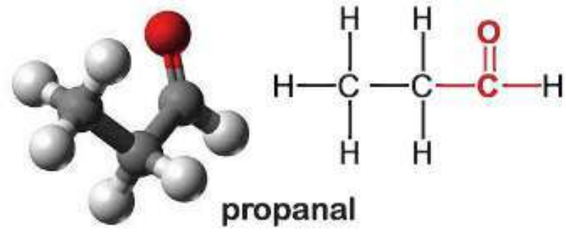
- **Examples**



methanal
(formaldehyde)
HCHO



ethanal
(acetaldehyde)
CH_3CHO

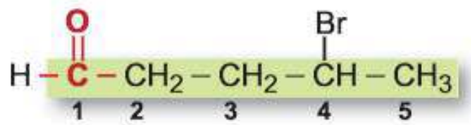


propanal
CH_3CH_3CHO

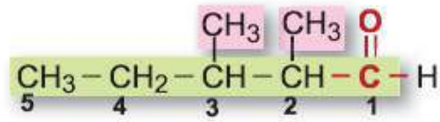
- **Naming of aldehydes**

1. Aldehydes end on the suffix **–al.**
2. The parent chain must contain the carbonyl group and numbering starts at the carbonyl group.
3. Number the substituents according to their positions and arrange them alphabetically in the final name.

- **Examples**

(1) 

4-bromopentanal

(2) 

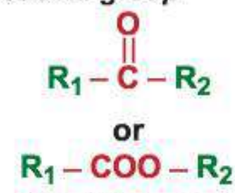
2,3-dimethylpentanal

8.2 KETONES

Ketones contain a carbonyl group with two organic groups attached to the C-atom of the carbonyl group.
The general formula for aldehydes $C_nH_{2n}O$ is the same as for the ketones.
The simplest ketone, propanone, therefore has three C-atoms.

The ketone functional group



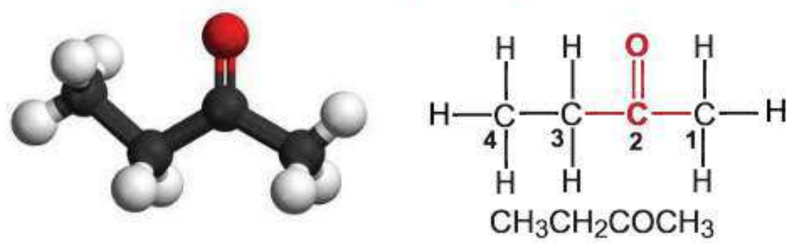


R_1 and R_2 = H, -CH_3, C_2H_5, ect

- **Examples**



propanone
(acetone)

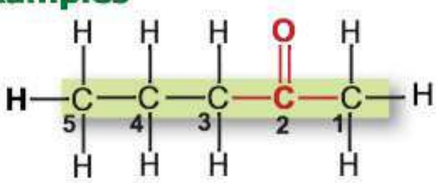


butan-2-one
(or 2-butanone)

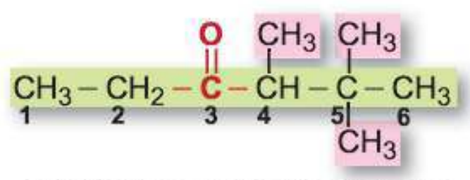
- **Naming of the ketones**

1. Ketones end on the suffix **–one.**
2. The parent chain must contain the carbonyl group and numbering is from the end nearest to the carbonyl group.
3. Record the number of the C-atom to which the double bond =O is attached in the final name.
4. Number the substituents according to their positions and arrange them alphabetically in the final name.

- **Examples**

(1) 

pentan-2-one

(2) 

4,5,5-trimethylheksan-3-one

States

Except for methanal a gas at room temperature all simple aldehydes and ketones are liquids.

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Solubility

Aldehydes and ketones are soluble in simple organic solvents, and those with less than five or six C-atoms also soluble in water because they are capable of forming hydrogen bonding with water molecules, they are excellent solvents because they can dissolve both polar and nonpolar compounds. With the increase in the number of C-atoms aldehydes and ketones, as the alkyl group becomes larger, become more like alkanes less soluble.

Uses

- Aldehydes and ketones contribute to the distinctive flavours of food and plants.
- The simplest aldehyde is methanal (also known as formaldehyde). It is a gas with a sharp pungent odour, used as disinfectant and for preservation. A aqueous solution thereof is known as formalin. It is mainly used to preserve biological samples, e.g. dead animals.





Vanilla, cinnamon and formalin is an example of where aldehydes are found.

- Ethanal (acetaldehyde) has a sweet flavour, flammable liquid present in ripe fruit,observed in apples. It is used in making ethanoic acid.
- Cinnamaldehyde is the organic compound that gives cinnamon its flavour. Cinnamaldehyde occurs naturally in the bark of cinnamon trees.
- Vanilla is an aldehyde which is found in vanilla beans and is used as a flavouring in foods and beverages. The vanilla bought in shops are synthetic and unnatural.
- A major ketone is fructose, or fruit sugar, used as a alternative, not fattening, natural sweetener in place of sugar.
- Acetone (propanone) is a ketone found in nail polish remover.
- Testosterone is again a ketone found in male sex hormones.





Fructose is a ketone which is used as a sugar replacement. Acetone is used in nail polish remover.

Exercise 9 ALDEHYDES AND KETONES

1. 1.1 What is the difference in structure between an aldehyde and a ketone?

_____

_____

_____

_____

_____

_____

1.2 Identify each of the following compounds as an aldehyde or ketone:

A. CH_3CHO B. CH_3COCH_3 C. $CH_3CH_2CH_3(CH_3)COCH_3$ D. $(CH_3)_3CCHO$

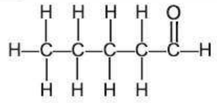
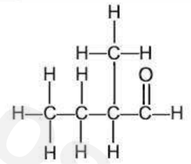
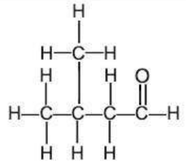
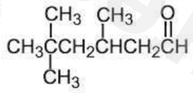
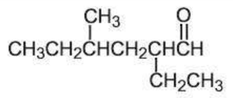
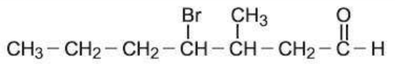
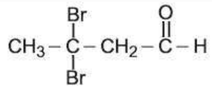
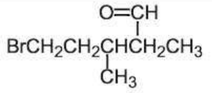
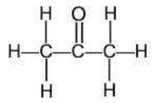
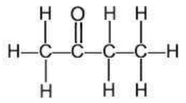
Aldehydes: _____ Ketones: _____

2. TWO structural isomers of C_4H_8O are aldehydes and ONE is a ketone. Draw each of the three compounds's structural formulae and give their IUPAC names.

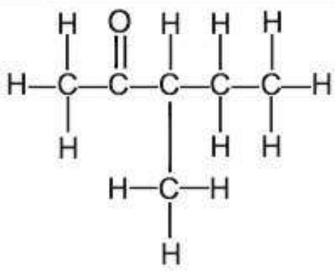
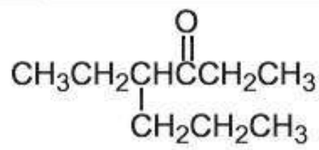
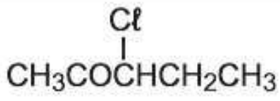
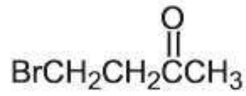
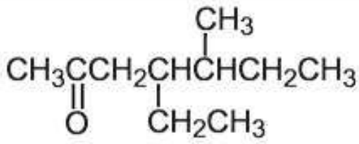
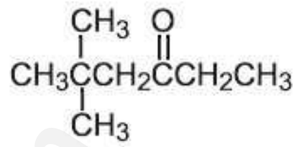
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3. FOUR structural isomers of $C_5H_{10}O$ are aldehydes and THREE are ketones. Draw each of the three compounds's structural formulae and give their IUPAC names.

4. Give the IUPAC names for each of the following aldehydes and ketones:

4.1 	4.2 
4.3 	4.4 
4.5 	4.6 
4.7 	4.8 
4.9 	4.10 

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4.11 $CH_3CH_2COCH_2CH_3$	4.12 $CH_3(CH_2)_2CO(CH_2)_2CH_3$
4.13 	4.14 
4.15 	4.16 
4.17 	4.18 

5. Draw the structural formulae of the following aldehydes and ketones:

5.1 3-methylpentanal

5.2 4,4-dibromo-2-methylhexanal

5.3 2,3,4,4-tetrachlorobutananal

5.4 3,5,5-trimethylhexanal

5.5 3-ethyl-4-methylhexanal

5.6 2-pentanone

5.7 propanone

5.8 1-iodopropanone

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5.9 3-bromo-2-butanone

5.10 4,4-dimethyl-3-hexanone

5.11 5-bromo-2-ethyl-3-methylpentanal

5.12 3,5,5-trimethylhexanal

6. Draw the condensed structural formulae of the following aldehydes and ketones:

6.1 3,3-diëthylheptanal

6.2 6-ethyl-3-methyloktanal

6.3 5-bromo-2-ethyl-3-methylpentanal

6.4 3-bromo-5,5-dimethylhexanal

6.5 4-ethyl-5-methyl-2-heptanone

6.6 4-ethyl-2-methyl-3-hexanone

6.7 1,1,1-trichloro-2-btanone

6.8 4-chloro-3,3-dimethyl-2-pentanone

6.9 2-ethyl-4-methylpentanal

6.10 2-methyl-3-pentanone

6.11 4-bromo-3-methylheptanal

6.12 4-bromo-2-butanone

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STRUCTURE AND PHYSICAL PROPERTY RELATIONSHIPS

CLASSIFICATION OF PHYSICAL PROPERTIES

Physical properties of chemical compounds include the following:

- **Melting point** is the temperature at which the solid and liquid states of a substance are in equilibrium. This is the temperature at which a solid changes to a liquid.
- **Boiling point** is the temperature at which the vapor pressure of the substance is equal to the atmospheric pressure. This is the temperature at which a liquid changes to a gas.
- **Vapor pressure** is the pressure exerted by a vapor at equilibrium with its solid or liquid in a closed system. This is the pressure exerted on a liquid or solid by the vapor molecules of that substance in the gas state (i.e. which they evaporated from) in a closed container.
- **Physical condition** refers to the states of matter - gas, liquid and solid.
- **Density** is the mass per volume of a substance and is measured in $g \cdot cm^{-3}$. This is the amount of particles that occur per volume.
- **Molecular shape** is the shape of the molecule, for example: linear, tetrahedral and octahedral.
- **Flammability** refers to how easy it is for a substance to burn or ignite and start to burn.
- **Volatility** is the extent to which a liquid can change into a vapor. It is the tendency of molecules on the surface of the substance to change into the gas state.
- **Viscosity** is a measure of a liquid's resistance to flow. The greater the viscosity, the less liquid the fluid (the more difficult it will be to flow).
- **Solubility** is how easily a non-polar solvent (eg. $CC\ell_4$) can dissolve in polar solvents (eg. H_2O).

The molecular structure of an organic compound affects its physical properties. The physical properties of an organic compound depends on the strength of the intermolecular forces in the substance. The general trend is that the stronger the intermolecular forces, the higher the boiling point, melting point, viscosity and density and the lower the vapor pressure.

INTERATOMIC FORCES AND INTERMOLECULAR FORCES

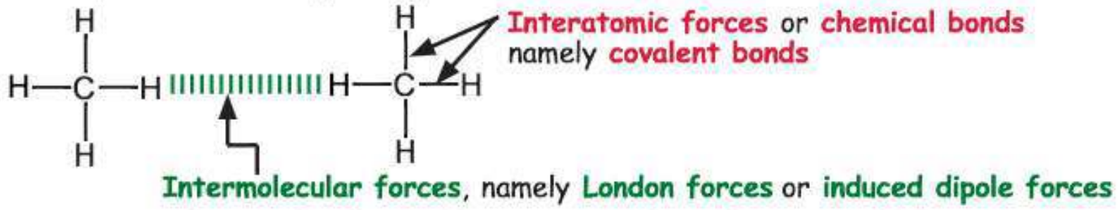
Interatomic forces (forces between atoms), also known as **intramolecular forces** involves the forces between atoms. It is also known as the **chemical bond**. An interatomic force or chemical bond is the electrostatic force of attraction between atoms due to the sharing or transfer of electrons. We distinguish between three types of interatomic forces or chemical bonds, namely:

- **Covalent bonds** - involves the reaction between two non-metallic atoms.
- **Ionic bonds** - involves the reaction between a metal and non-metallic atom.
- **Metallic bonds** - involves the reaction between atoms of metals.

Intermolecular forces is the force of attraction between molecules. Intermolecular forces (forces between molecules) are weaker than the interatomic forces. This means that the energy needed to break the forces between atoms (bonding energy) is greater than the energy required to break intermolecular forces.

In organic chemistry, we distinguish between the following intermolecular forces:

- **Van der Waal's forces**, namely:
  - **London forces or induced dipole forces**. Forces between non-polar molecules.
  - **Dipole-dipole forces**. Forces between two polar molecules.
- **Hydrogen bonds**. Forces between molecules in which hydrogen is covalently bonded to nitrogen, oxygen or fluorine, which is a special case of dipole-dipole forces.



By breaking the interatomic forces the chemical properties of a substance will change. Intermolecular forces determine the **physical properties of a substance**. If the intermolecular forces break, the physical condition of a substance changes. Liquid methane $CH_4(\ell)$ changes, for example, to methane gas $CH_4(g)$. The chemical properties are still that of methane.

INTERMOLECULAR FORCES BETWEEN ORGANIC MOLECULES

To understand and explain the physical properties of organic molecules, we first need to understand the difference between Van der Waal's forces (London or induced forces and dipole-dipole forces) and hydrogen bonding.

1. Van der Waal's forces

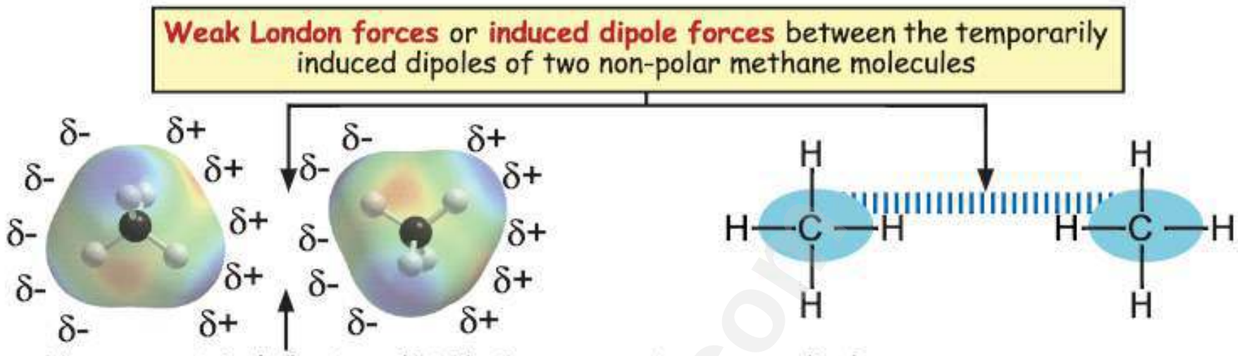
Van der Waal's forces are weak bonding forces which holds molecules together in the solid and liquid states. Based on the nature of functional groups involved in organic molecules, we distinguish between two types of Van der Waal's

forces namely London forces or induced dipole forces and dipole-dipole forces.

1.1 London forces or induced dipole forces between non-polar molecules

When two **non-polar molecules** approach each other or collide for a moment, forces of attraction and forces of repulsion arise between the electrons and nuclei of the atoms of the molecules. This causes an uneven distribution of charges in the molecule, which means that at a given moment, the electron density is not symmetrical and this causes a temporarily induced dipole and each molecule has one side slightly negative (δ-) and the other slightly positive (δ +). Through a chain reaction a **temporary dipole** is also induced in a neighbouring molecule. The result is weak forces of attraction between the molecules known as **weak London forces or induced dipole forces.**

Although a non-polar methane molecule (CH_4), for example, has no permanent (or net molecular) dipole, the electron density will not be fully symmetrical at any given moment and creates a temporary dipole. This induces another temporary dipole in another methane molecule with partially positive and negative charges arranged closely together. This weak interaction between temporary dipoles form induced **London forces or induced dipole forces.**



All organic molecules contain London forces or induced dipole forces.

- Among the non-polar molecules of alkanes, alkenes and alkynes are **London forces** (induced dipole forces) the **only** type of intermolecular forces which occurs between the molecules.
- At the polar molecules of the haloalkanes, aldehydes, ketones and esters where dipole-dipole forces occur between their molecules and with alcohols and carboxylic acids where strong hydrogen bonds and dipole-dipole forces occur between their molecules, weak **London forces** (induced dipole forces) also occur between the temporarily induced dipoles of the non-polar alkyl groups of these polar molecules.

• Contact surface (surface area) of molecules and London forces (or induced dipole forces)

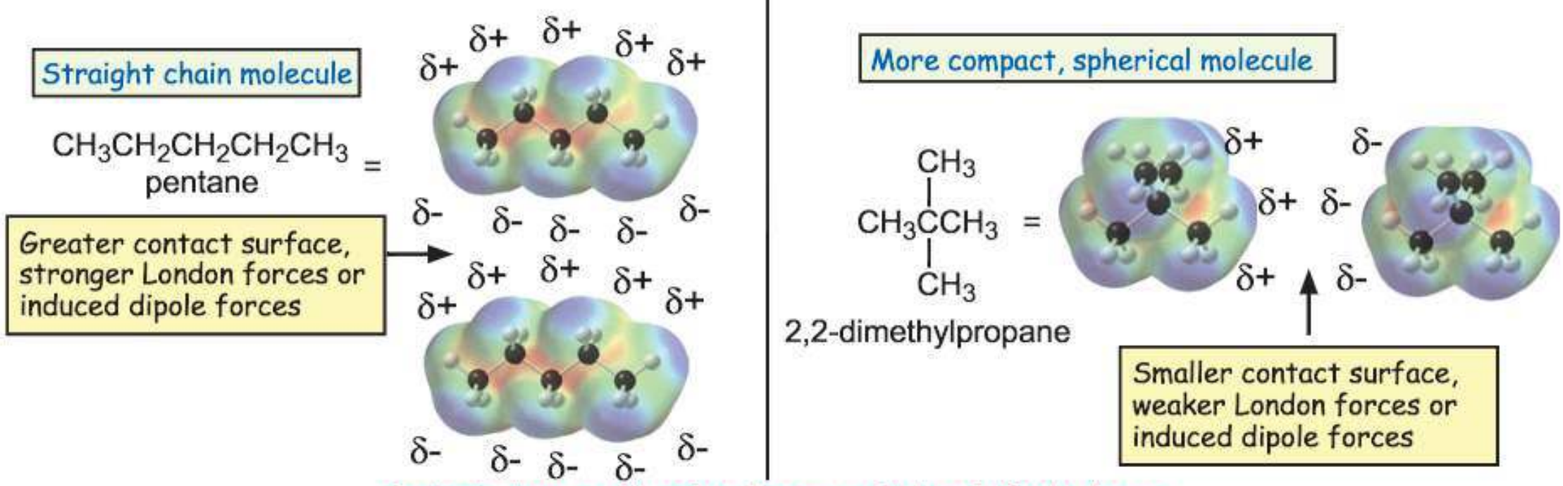
The greater the contact area, the greater the forces of attraction between the molecules and the stronger the London forces (induced dipole forces) between molecules.

Molecules with a longer chain length

- consists of long chain molecules (long sausage-like molecules)
- the molecule is less compact
- has **greater contact surfaces** which are in contact with each other over which London forces (induced dipole forces) can work
- can thus get much closer together, have more points of contact for London forces (induced dipole forces) to form (than branched chain molecules).

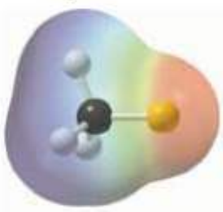
Molecules with branched chains

- forms molecules that are more spherical
- the molecules are more compact
- has **smaller contact surfaces** which are in contact with each other over which London forces (induced dipole forces) can work
- can thus not be as close together, have fewer points of contact for London forces (induced dipole forces).

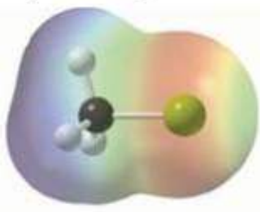


Contact Area and London forces or induced dipole forces

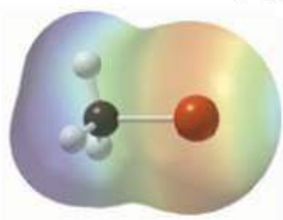
- **Increase in the size of the halogen atoms (X = F, Cℓ, Br or I) and London forces (or induced dipole forces)**
  - For the same alkyl group (CH_3-part) with F<Cℓ<Br<I, F is the smallest halogen atom with the least electrons and I the greatest halogen atom with the most electrons.
  - Larger atoms's electrons, such as I, are not as tightly held by their atoms (are further away from the nucleus) and are easily polarized, thus they can more easily form induced dipoles than the smaller atoms.
  - The larger the halogen atom, the larger the molecule for the same alkyl group RF < RCℓ < RBr < RI.



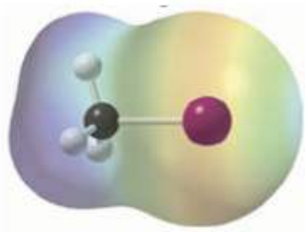
fluoromehtane
CH_3F



chlorometane
$CH_3Cℓ$



bromomethane
CH_3Br



iodomethane
CH_3I

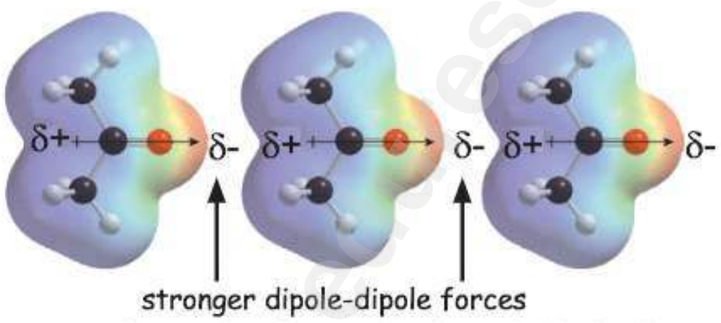
- The larger the halogen atom (greater atomic number with increasing number of electrons from F to I) the greater the haloalkane molecule (greater molecular mass) for the same alkyl group, CH_3I < $CH_3Cℓ$ < CH_3Br < CH_3I.
- I in CH_3I (the halogen atom size) is a **more polarizable** halogen atom (larger halogen atoms form induced dipoles more easily than smaller halogen atoms).
- **London forces** (induced dipole forces) grow stronger as the haloalkane molecule gets bigger thus as the halogen atom gets bigger and more polarizable for the same alkyl group.

1.2 Dipole-dipole forces between polar molecules

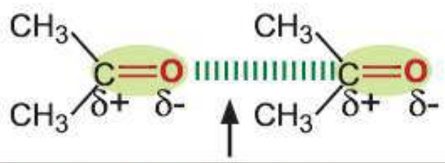
When atoms with different electronegativities bond to form a molecule and the shape of the molecule is non symmetrical, an uneven charge distribution occurs in the molecule. This uneven charge distribution of charges causes a **polar molecule** to exist and the molecule contains two distinctly opposite poles and is called a **permanent dipole** (polar dipole or net dipole) the one end of the molecule slightly negative (δ-) and the other end of the molecule slightly positive (δ +).

When **polar molecules** are near one another, forces of attraction arise between the opposite poles of different polar molecules. These intermolecular forces (forces of attraction) are known as **dipole-dipole forces**. **Dipole-dipole forces** are **stronger** than London forces (induced dipole forces).

The following figure shows the dipole-dipole forces between the polar areas or permanent dipoles (polar dipole or net dipole) of the molecules of propanone.



stronger dipole-dipole forces

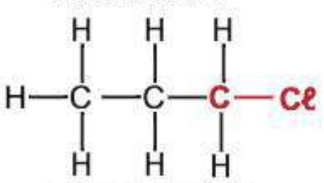


Strong dipole-dipole forces between the permanent dipoles of the polar areas of the polar propanone molecule

Remember: • Weak **London forces (induced dipole forces)** are always present **in all molecules.**
• Weak **London forces (induced dipole forces)** occur between the temporarily induced dipoles of the non-polar alkyl groups.

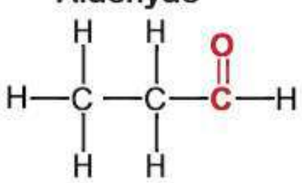
For example, consider the following organic molecules.

Haloalkane



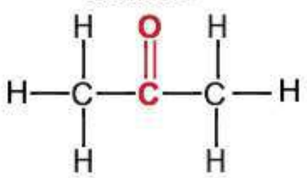
$CH_3CH_2CH_2Cℓ$
1-chloropropane
London forces (induced dipole forces)
+ dipole-dipole forces

Aldehyde



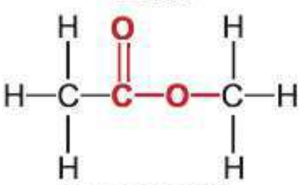
CH_3CH_2CHO
propanal
London forces (induced dipole forces)
+ dipole-dipole forces

Ketone



CH_3COCH_3
propanone
London forces (induced dipole forces)
+ dipole-dipole forces

Ester



CH_3COOCH_3
methyl methanoate
London forces (induced dipole forces)
+ dipole-dipole forces

- 1-chloropropane : Is a polar molecule. Has a permanent dipole (polar dipole) due to the C-Cℓ bond.
- Propanal : Is a polar molecule. Has a permanent dipole (polar dipole) due to the C=O bond.
- Propanone : Is a polar molecule. Has a permanent dipole (polar dipole) due to the C=O bond.
- Methyl methanoate : Is a polar molecule. Has a permanent dipole (polar dipole) due to the C=O and C-O bonds.

- All these molecules also contain non-polar alkyl groups.
- *Type of intermolecular forces between the molecules*:
  Weak London forces (induced dipole forces) between the temporarily induced dipoles of the non-polar alkyl groups (all molecules contain weak London or induced dipole forces).
  Dipole-dipole forces *between permanent dipoles* (polar dipole) due to the polar bonds.
- *Strongest (main type) intermolecular forces present*: **Dipole-dipole forces**

Between polar molecules (of haloalkanes, ketones and esters) are dipole-dipole forces in addition to weak London forces (induced dipole forces).

2 Hydrogen Bonds

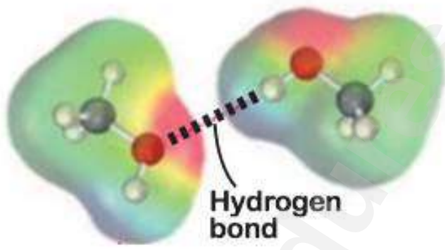
Hydrogen Bonds are special types of dipole-dipole forces that occur between polar molecules O-H, N-H, or F-H bonds, and takes place when the H-atom of a molecule that is covalently bonded to a highly electronegative atom such as O, N or F is electrostatically attracted to an O, N or F atom of another molecule. Hydrogen bonding are much stronger than London forces (induced dipole forces) and dipole-dipole forces.

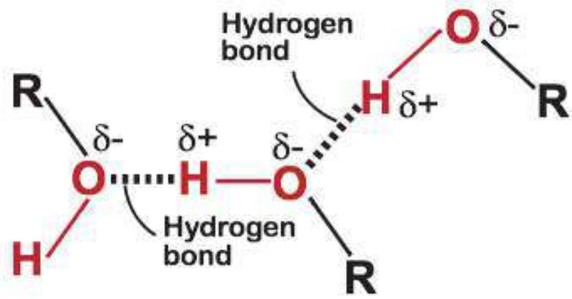
Weak London forces (induced dipole forces) <Strong dipole-dipole forces <Stronger hydrogen bonding

At organic molecules **hydrogen bonds** are found **between the polar parts of the highly polar molecules** of **alcohol** and also between the molecules of **carboxylic acids**.

2.1 Alcohol molecules

- Contain a hydroxyl group (**OH**-group) bonded to a carbon atom.
- Are polar molecules. Have permanent dipoles (polar dipole) as a result of the polar C-O and O-H bonds.
- Also contain non-polar alkyl groups.
- *Types of intermolecular forces between the alcohol molecules*:
  Weak London forces (induced dipole forces) *between temporary dipoles* of the non-polar alkyl groups.
  Dipole-dipole forces between permanent dipoles (polar dipoles) as a result of the polar C-O and O-H bonds.
  Strong **hydrogen bonds** (**O-H····O-H**) between the **OH**-groups (hydroxyl groups) of the molecules.
- *Strongest (main type) intermolecular forces present*: **Hydrogen Bonds**
- Only **one hydrogen bond** can form between each polar -**O-H** group of two alcohol molecules.
- There is only **one point** for a hydrogen bond for each **O-H** group.
- **Besides dipole-dipole forces and weak London forces (induced dipole forces) alcohols also have strong hydrogen bonds between molecules.**



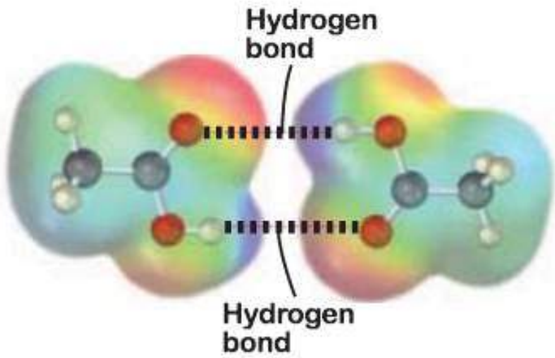


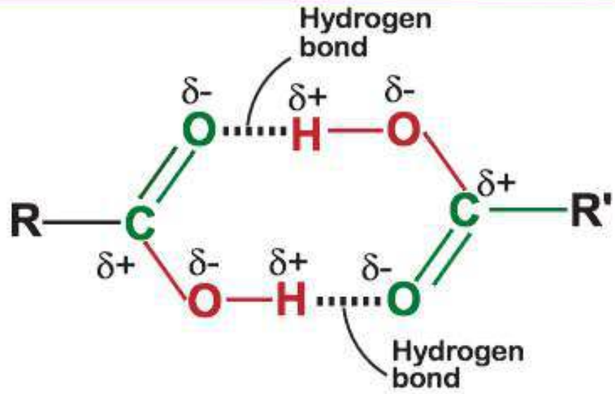
Each alcohol molecule contains an O-H bond (OH group) for hydrogen bonds.
Only ONE hydrogen bond is possible between neighboring alcohol molecules.

Between alcohol molecules there are strong hydrogen bonds in addition to dipole-dipole forces and weak London forces (induced dipole forces).

2.2 Carboxylic acid molecules

- Contains a carboxyl group (**COOH**-group) consisting of a hydroxyl group (**OH**-group) bonded to a C-atom and a carbonyl group (**C=O**-group), where an O-atom is bonded to a C-atom.
- Are polar molecules. Permanent dipoles (polar dipole) due to the polar C=O, C-O and O-H bonds.
- Also contains non-polar alkyl groups.
- *Type of intermolecular forces between the alcohol molecules*:
  Weak London forces (induced dipole forces) between temporary dipoles of the non-polar alkyl groups.
  Dipole-dipole forces between permanent dipoles due to the polar C=O, C-O and O-H bonds.
  Strong **hydrogen bonds** (**O-H····O=C**) between the **OH**-group of one molecule and the **C=O** group of the other molecule.
- *Strongest (main type) intermolecular forces present*: **Hydrogen Bonds**
- **Two hydrogen bonds** (dimer) can form between neighbouring carboxylic acid molecules due to the presence of the **OH**-group and the **C=O**-group in every carboxylic acid molecule.
- There are **two points** available for hydrogen bonds.
- **Besides dipole-dipole forces and weak London forces (induced dipole forces) carboxylic acids also have strong hydrogen bonds (2 × hydrogen bonds) between molecules.**





Each carboxylic acid molecule contains a COOH-group with an O-H-bond and a C=O-bond. The O-H group in a molecule forms hydrogen bonds with the C=O group in the other molecule. It forms TWO hydrogen bonds (dimer) between neighboring carboxylic acid molecules.

Between carboxylic acid molecules are strong hydrogen bonds (2 x hydrogen bonds) in addition to dipole-dipole forces and weak and London forces (induced dipole forces).

■ Summary

The following table summarizes the **intermolecular forces** that occur between the organic molecules:

INTERMOLECULAR FORCES BETWEEN ORGANIC MOLECULES		
Van der Waal's forces		**Hydrogen Bonds**
London forces or induced dipole forces	**Dipole-dipole forces**	
Weak forces of attraction between temporarily induced dipoles of non-polar molecules and temporarily induced dipoles of alkyl groups of organic molecules.	The forces of attraction between the permanent dipoles (polar dipoles) of polar molecules and are stronger than London forces (induced dipole forces).	Is the strongest of all the intermolecular forces. Occurs between highly polarized molecules in which H is covalently bonded to N, O or F in a special form of dipole-dipole forces.
Examples		
Between all molecules • Between the temporarily induced dipoles of the **non-polar molecules** of the alkanes, alkenes and alkynes. • Between the temporarily induced dipoles of the non-polar alkyl groups of haloalkanes, aldehydes, ketones, esters, alcohols and carboxylic acids	Between the **permanent dipoles** (polar dipole) of the following **polar molecules**: • Haloalkanes (R-X bond) • Aldehydes (C=O bond) • Ketones (C=O bond) • Esters (C=O and C-O bonds) • Alcohols (C-O and O-H bonds) • Carboxylic acids (C-O, C-H and C=O bonds)	Between the highly polar molecules of the alcohols and carboxylic acids: • Alcohols have an O-H bond (OH hydroxyl group) for hydrogen bond 1 × (**O-H····O-H**) • Carboxylic acids have an O-H bond (OH hydroxyl group) and a C = O bond (C = O carbonyl group) for hydrogen bonds. 2 × (**O-H···· O=C**)
Among the non-polar molecules of alkanes, alkenes and alkynes there are **weak London forces** (induced dipole forces). • Between the polar molecules of the haloalkanes, aldehydes, ketones and esters there are **dipole-dipole forces** In addition to weak London forces (induced dipole forces). • Between the strong polar molecules of alcohols and carboxylic acids there are **strong hydrogen bonds** in addition to dipole-dipole forces and weak London forces (induced dipole forces). (Carboxylic acids forms 2 × hydrogen bonds compared to the 1 × hydrogen bond which forms at alcohols.)		

RELATIONSHIP BETWEEN PHYSICAL PROPERTIES AND STRUCTURE OF ORGANIC MOLECULES

We will now look at what relationship exists between the physical properties namely **melting point, boiling point and vapor pressure** of organic molecules and their structure in terms of the:

- strength of the intermolecular forces (type of functional group)
- number of functional groups of the same type,
- chain length or molecular mass,
- branched chains.

1. RELATIONSHIP BETWEEN MELTING POINT, BOILING POINT, VAPOR PRESSURE AND THE STRENGTH OF THE INTER MOLECULAR FORCES (TYPE OF FUNCTIONAL GROUP)

Melting point is the temperature at which the solid and liquid states of a substance are in equilibrium.
Boiling point is the temperature at which the vapor pressure of a substance equals the atmospheric pressure.
Vapor pressure is the pressure exerted by a vapor in equilibrium with its liquid or solid in a closed system.

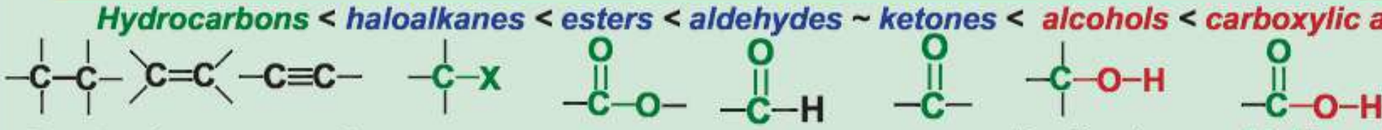
The **type and strength** of the forces of attraction between the molecules of a compound in the liquid and solid states are determined by the **type of functional group** in the compound. The more polar the functional group, the more polar the molecule, and the stronger the intermolecular forces between the molecules. The presence of **O-H** bonds in a functional group further adds to the formation of strong hydrogen bonds that result in even stronger intermolecular forces.

The **stronger the intermolecular forces** (e.g. hydrogen bonds are stronger than dipole-dipole forces which in turn are stronger than London or induced dipole forces) are between the molecules of a compound, the more energy is required to overcome the forces and the **higher the melting point and boiling point**, and the lower the vapor pressure of the compound.

Strength of the intermolecular forces (type of functional group)

Increase in polarity of the type of functional group

Hydrocarbons < haloalkanes < esters < aldehydes ~ ketones < alcohols < carboxylic acids



- Functional group **non-polar**
- Temporary induced dipoles for **London forces** (induced dipole forces)

- Functional **polar** group: permanent dipoles (polar dipole) for **dipole-dipole forces**
- Non-polar alkyl groups with temporary induced dipoles for **London forces** (induced dipole forces)
- No **O-H-** bonds and can thus not form hydrogen bonds

- Functional group **highly polar,** permanent dipoles (polar dipoles) for **dipole-dipole forces**
- **O-H**-bonds for **hydrogen bonding**
- Non-polar alkyl groups with temporary induced dipoles for **London forces** (induced dipole forces)

Increase in strength of intermolecular forces (intermolecular forces α polarity of type of functional group)

London forces (induced dipole forces) **< dipole-dipole forces < hydrogen bonds**

- ***Melting point and boiling point increases with increasing strength of intermolecular forces***
- ***Vapor pressure decreases with increasing strength of intermolecular forces***

Molecular structure :Type of functional group which is strongly polar with O-H-bonds
Intermolecular forces :Stronger (more) intermolecular forces
Energy :More energy is required to overcome (to break) intermolecular forces

- ***Independent variable*** (is changed) : Type of functional group (Type of homologous series or compound)
- ***Dependent variable*** (is measured) : Melting point or boiling point or vapor pressure
- ***Controlled variable*** (remains the same) : The same number of C-atoms, the same (comparable) molecular mass

Compare the melting points, boiling points and vapor pressure of the organic compounds in the following table with the same number of C-atoms but with different functional groups with regard to the type and strength of the intermolecular forces between the molecules.

Compound	Molecular formula	Molecular mass ($g \cdot mol^{-1}$)	Melting point (°C)	Boiling point (°C)	Vapor pressure (kPa at 20 °C)	Type and strength of the intermolecular forces
Ethane	C_2H_6	30	-183	-89	3 750	Only **weak London forces** (induced dipole forces) are between the molecules
Chloroethane	$C_2H_5C\ell$	64,5	-136	12	132,4	**Stronger dipole dipole forces** in addition to weak London forces (induced dipole forces) are between the molecules
Ethanol	C_2H_5OH	46	-89	78	5,8	**Strong hydrogen bonds** in addition to dipole-dipole forces and weak London forces (induced dipole forces) are between the molecules
Ethanoic-acid	C_2H_5COOH	60	16	118	1,6	**Very strong hydrogen bonds** (2 × hydrogen bonds) in addition to **dipole-dipole** forces and weak London- forces (induced dipole forces) are between the molecules

- **Ethane**: functional group is **non-polar**. Temporary induced dipoles for **London forces** (induced dipole forces).
- **Chloroethane**: functional group is **polar**. Permanent dipoles (polar dipole) for **dipole-dipole forces**. Non-polar alkyl groups with temporary induced dipoles for **London forces** (induced dipole forces). No **O-H**-bonds and can thus not form hydrogen bonds. **Dipole-dipole forces > London forces**
- **Ethanol and ethanoic acid**: functional groups strongly polar: Permanent dipoles (polar dipole) for **dipole-dipole forces**. Each has an **O-H**-bond for **hydrogen bonds**. Non-polar alkyl groups with temporary induced dipoles for **London forces** (induced dipole forces). **Hydrogen bonds> dipole-dipole forces> London forces**

Example 1

The boiling points of butan-1-ol and propanoic acid are investigated and studied in practice. The results are as follows:

Compound	IUPAC name	Molecular mass ($g \cdot mol^{-1}$)	Boiling point (°C)
$CH_3CH_2CH_2CH_2OH$	butan-1-ol	74	118
CH_3CH_2COOH	propanoic acid	74	141

1.1 Give the independent variable (which is changed).
1.2 Give the dependent variable (which is measured).
1.3 Give the controlled variable (which remains the same). (Ignore environmental factors such as temperature and pressure).
1.4 Give an appropriate investigative question.
1.5 Give a conclusion to the investigation.
1.6 Give an explanation for your answer to Question (5).

Answer

1.1 Type of functional group (type of homologous series or compound type).
1.2 Boiling Point
1.3 Molecular mass
1.4 What is the relation between the functional group and the boiling point of organic compounds with the same molecular mass?
1.5 The boiling points of carboxylic acids are higher than the boiling points of haloalkanes and alcohols with the same molecular mass.
1.6 Between alcohol molecules there are **strong hydrogen bonds** (1× hydrogen bond) in addition to weak London forces (induced dipole forces) and dipole-dipole forces.
Between carboxylic acid molecules there are **very strong hydrogen bonds** (2× hydrogen bonds) in addition to weak London forces (induced dipole forces) and dipole-dipole forces.
The carboxyl groups (COOH-group consisting of a C=O carbonyl group and a hydroxyl group OH) of two carboxylic acid molecules can form **two hydrogen bonds** with each other compared to alcohols where the OH-groups (hydroxyl groups) of 2 molecules can only form **one hydrogen bond**.
Carboxylic acids thus has stronger intermolecular forces than those of alcohols with the same (comparable) mass.
More energy is required to separate carboxylic acid molecules.
Thus, carboxylic acids have higher boiling points.

Example 2

Three bottles containing respectively pentane, pentanal and pentanol at room temperature.



The molecular formula, molecular mass and vapor pressure for each of these compounds are as follows:

Compound	Molecular formule	Molecular mass ($g \cdot mol^{-1}$)	Vapor pressure (kPa by 20°C)
Pentaan	C_5H_{12}	72	60
Pentanal	$C_5H_{10}O$	86	4,7
Pentanol	$C_5H_{11}OH$	88	0,29

The vapor pressure of the alcohol (pentanol) is much lower than that of the aldehyde (pentanal) and alkane (pentane) with the same number of C-atoms. Explain this observation by referring to the type and strength of the intermolecular forces in alkanes, aldehydes and alcohols.

Answer

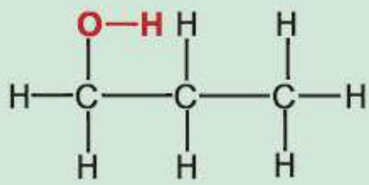
Between molecules of alkanes only **weak London forces** (induced dipole forces) are present.
Between aldehyde molecules are stronger **dipole-dipole forces** in addition to weak London forces (induced dipole forces).
Between molecules of the alcohols are **strong hydrogen bonds** in addition to weak London forces (induced dipole forces) and dipole-dipole forces.
Hydrogen bonds> **dipole-dipole forces**> **London forces** (induced dipole forces)
Much more energy is required to overcome the intermolecular forces between the alcohol molecules in order to change from a liquid state to a gas state.
Alcohols (pentanol) are less volatile and therefore have the lowest vapor pressure.

2 RELATIONSHIP BETWEEN MELTING POINT, BOILING POINT, VAPOR PRESSURE AND THE NUMBER FUNCTIONAL GROUPS OF THE SAME TYPE

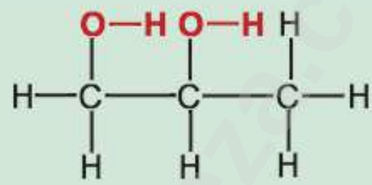
The more halogen atoms (F, Cℓ, Br, I), or OH-groups, or CO-groups or CHO-groups or COOH-groups are present in the compound, **the stronger the intermolecular forces become**, so that **more energy is required to overcome** (break) these **stronger intermolecular forces** and the **higher the melting point and boiling point**, and the **lower the vapor pressure** of the compound.

Number of functional groups of the same type

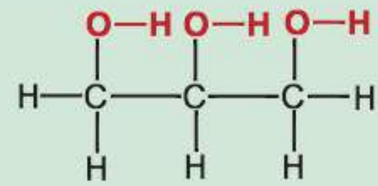
Increase in the number functional groups of the same type in the compound, more points for intermolecular forces between the functional groups



propan-1-ol
molecular mass = 60 g·mol^{-1}
melting point = -126 °C
boiling point = 98 °C
vapor pressure = 2 kPa at 21 °C
One point for a hydrogen bond



propan-1,2-diol
molecular mass = 76 g·mol^{-1}
melting point = -59 °C
boiling point = 188 °C
vapor pressure = 0,01 kPa at 21 °C
Two points for hydrogen bonds



propan-1,2,3-triol
molecular mass = 92 g·mol^{-1}
melting point = 17,8 °C
boiling point = 290 °C
vapor pressure = 0,008 kPa at 21 °C
Three points for hydrogen bonds

Increase of the same functional group →

Increase in strength of intermolecular forces
(intermolecular forces α number of the same functional group)

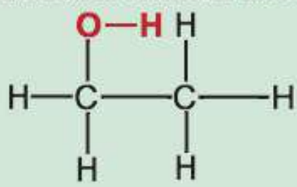
- ***Melting point and boiling point increases with the increase of the same functional group***
- ***Vapor pressure decreases with the increase of the same functional group***

Molecular structure: Increase of the same functional group in the compound
Intermolecular forces: Stronger (more) intermolecular forces
Energy: More energy is required to overcome intermolecular forces (to break)

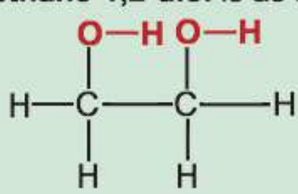
- ***Independent variable*** (that is changed) : Number of the same functional groups
- ***Dependent variable*** (that is measured) : Melting point or boiling point or vapor pressure
- ***Controlled variable*** (that remains the same): The same number of C-atoms. Identity of the functional group. The same type of homologous series

Example 3

The structural formula and boiling point for **ethanol** and **ethane-1,2-diol** is as follows:



ethanol
boiling point = 78,5 °C



ethan-1,2-diol
boiling point = 197,3 °C

3.1 Consider the boiling points of these alcohols and describe the trend in their boiling points.
3.2 Explain the trend in Question (1) fully.
3.3 Which of these two compounds has the highest vapor pressure? Refer to their boiling points as a reason for the answer.

Answer

3.1 • The boiling point increases as the number of **OH**-groups increase from ethanol to ethan-1,2-diol.
• The boiling point is *directly proportional* to the quantity of **OH**-groups if the number of **C**-atoms and identity (type) of the **OH**-groups remain constant.

3.2 • Because of the **O-H**-bonds (of the **OH**-groups) in alcohols there are strong **hydrogen bonds** between alcohol molecules in addition to dipole-dipole forces and weak London forces (induced dipole forces).
• As the number of **OH**-groups increase, there are more points for hydrogen bonds and the strength of the hydrogen bonds increase from ethanol (1 point for H-bonding) to ethan-1,2-diol (2 points for H-bonds).
• More energy is required to overcome the intermolecular forces between the molecules of ethan-1,2-diol than between the molecules of ethanol.

3.3 Ethanol. Has the lowest boiling point.

Example 4

The vapor pressure of the following four haloalkanes are investigated and studied. The results are as follow:

Haloalkane	Molecular formula	Vapor pressure (kPa at 20°C)
Bromomethane	CH_3Br	189
Dibromomethane	CH_2Br_2	5
Tribromomethane	$CHBr_3$	0,67
Tetrabromomethane	CBr_4	0,01

4.1 Provide the independent variable (which is changed).
4.2 Give the dependent variable (which is measured).
4.3 Give the controlled variable (which remains the same). (Ignoring environmental factors such as temperature and pressure).
4.4 Provide an appropriate investigative question.
4.5 Provide a conclusion to the investigation.
4.6 What intermolecular forces are responsible for the difference in the vapor pressure at these compounds?
4.7 Will the boiling point of tetrabromomethane be GREATER THAN or LESS THAN that of dibromomethane? Refer to MOLECULAR STRUCTURE, INTERMOLECULAR FORCES and ENERGY needed to explain the answer.
4.8 Which one of these four haloalkanes has the lowest boiling point? Refer to vapor pressure to give a reason for the answer.

Answer

4.1 Number of Br-atoms (the same number of halogen atom) (type of haloalkane).
4.2 Vapor pressure
4.3 Number of C-atoms (identity of the halogen atom)
4.4 What is the relation between number of Br-atoms and the vapor pressure of haloalkanes with the same number of C-atoms?
4.5 The vapor pressure of haloalkanes is inversely proportional to the number of halogen atoms (Br-atoms) present if the number of C-atoms and the identity of the halogen atom remains constant.
4.6 London forces (induced dipole forces), which increases with each substitution of a hydrogen atom with a Br-atom. (London forces increase with increase in the size of halogen atom for the same alkyl group.)
4.7 Higher than

Structure:
More Br-atoms present. (More Br atoms for the same number of C-atoms.)

Intermolecular forces:
Stronger or more intermolecular forces.

Energy:
More energy is required to overcome intermolecular forces.

4.8 Bromomethane. Has the highest vapor pressure (most volatile).

3 RELATIONSHIP BETWEEN MELTING POINT, BOILING POINT, VAPOR PRESSURE AND THE CHAIN LENGTH

The **longer the carbon chain**, the **more C-atoms** are in the compound the **larger the molecular mass** and the **stronger the London forces** (induced dipole forces) between molecules.
Longer chains have less compact molecules with a **larger contact area** across which the intermolecular forces can work. **More energy** is therefore needed to overcome the stronger London forces (induced dipole forces) and the **higher the melting point and boiling point**, and the **lower the vapor pressure** of the compound.

CHAIN LENGTH

More C-atoms in the chain, longer chain length, larger molecules, greater molecular mass, are less compact molecules with larger contact area

$CH_3CH_2CH_2CH_3$	$CH_3CH_2CH_2CH_2CH_3$	$CH_3CH_2CH_2CH_2CH_2CH_3$
butane	pentane	hexane
molecular mass = 58 $g{\cdot}mol^{-1}$	molecular mass = 72 $g{\cdot}mol^{-1}$	molecular mass = 186 $g{\cdot}mol^{-1}$
melting point = -138 °C	melting point = -130 °C	melting point = -95 °C
boiling point = -0,5 °C	boiling point = 36 °C	boiling point = 69 °C
vapor pressure = 204 kPa at 21 °C	vapor pressure = 56,8 kPa at 21 °C	vapor pressure = 17,6 kPa at 21 °C
London forces or induced dipole forces	London forces or induced dipole forces	London forces or induced dipole forces

Size of the contact area increases across which the intermolecular forces work

→

Increase in strength of London forces (induced dipole forces)
(Intermolecular forces α size of the molecule and chain length)

- ***Melting point and boiling point increase with increase in size of the molecules and chain length***
- ***Vapor pressure decreases with increase in size of the molecule and chain length***

Molecular structure :Longer chains with less compact molecules that have a larger surface which the intermolecular forces work across.
Intermolecular forces :Stronger (more) intermolecular forces
Energy :More energy is required to overcome (to break) intermolecular forces

- ***Independent variable*** (that is changed) : Length of the carbon chain
- ***Dependent variable*** (that is measured) : Melting point or boiling point or vapor pressure
- ***Controlled variable*** (that remains the same) : The same number of C-atoms. Identify of the functional group. Same type of homologous series

Study the following table of melting points, boiling points and vapor pressure of a number of linear alkanes:

n	Name	Molecular formula	Molecular mass ($g{\cdot}mol^{-1}$)	Melting point (°C)	Boiling point (°C)	Vapor Pressure (kPa at 20 °C)	State at room temperature
1	Methane	C_2H_4	16	-183	-162	Very High	gas
2	Ethane	C_3H_6	30	-182	-88	3 850	gas
3	Propane	C_3H_8	44	-187	-25	843	gas
4	Butane	C_4H_{10}	58	-138	-0,5	204	gas
5	Pentane	C_5H_{12}	72	-130	36	56,8	liquid
6	Hexane	C_6H_{14}	86	-95	69	17,6	liquid
7	Heptane	C_7H_{16}	100	-91	98	5,33	liquid
8	Octane	C_8H_{18}	114	-56	126	1,47	liquid
9	Nonane	C_9H_{20}	128	-51	151	1,33	liquid
10	Decane	$C_{10}H_{22}$	142	-30	174	0,17	liquid
18	Octadecane	$C_{18}H_{38}$	254	28	316	- - -	solid
19	Nonadecane	$C_{19}H_{40}$	268	32	329	- - -	solid

By considering the melting points, boiling points and vapor pressure of the first ten alkanes in the table above, we can derive and explain the following tendency:

Trend of melting points, boiling points and vapor pressure:

- The melting and boiling points increase from methane to decane.
- The vapor pressure decreases from methane to decane.

Explanation for this trend:

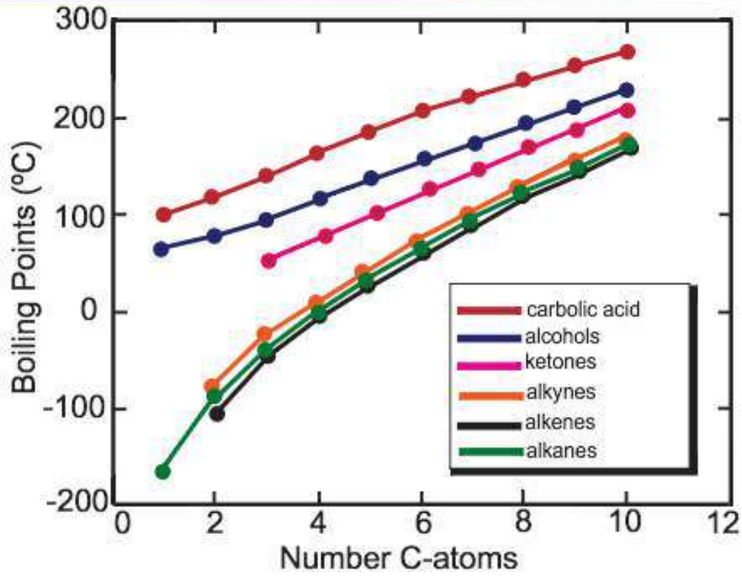
- The molecular mass, number of C-atoms, chain length and size of the molecule increase from methane to decane.
- Contact surface over which the **London forces** (induced dipole forces) work increases from methane to decane.
- Strength of the **London forces** (induced dipole forces) increase from methane to octane.
- More energy is required to break or overcome the intermolecular forces in decane than methane.

NOTE!

For **compounds of the same homologous series**: as the number of C-atoms in the chain increase, the length of the alkyl part increases, the size of the molecules increases (greater molecular masses) and there is a larger surface area.

The molecule becomes more alkane like. The **London forces** (induced dipole forces) between the longer molecules **also increase** (becomes stronger) and **increases** the **melting points and boiling points** and **lowers the vapor pressure** of compounds. **London forces** (induced dipole forces) dominate the effect of dipole-dipole forces and hydrogen bonding in larger molecules.

The chart on the right shows the boiling points versus the number C-atoms for different homologous series. From the graph lines we see that as the number of C-atoms in the organic compound increases, the boiling points increase. It also appears that the boiling points form a straight line graph for the higher members of each group.



Graph of the melting points versus number of C-atoms for different homologous series.

- Boiling points are directly proportional to the chain length (length of the alkyl group, increase in number of C-atoms, molecular size or molecular mass).
- Longer chains have larger surface areas over which the **London forces** (induced dipole forces) can work.
- Stronger (more) intermolecular forces between longer chains (i.e. the longer the alkyl part becomes).
- More energy is required to overcome intermolecular forces.

Example 5

The table below shows the results obtained from experiments to determine the boiling points of some alkenes, alkanes and alcohols of similar molecular weight:

Compound	Relative Molecular Mass	Boiling Point (°C)
$CH_2=CH_2$	28	-104
CH_3OH	32	65
$CH_2CH=CH_2$	42	-47
CH_3CH_2OH	46	78
$CH_2CH_2CH=CH_2$	56	7
$CH_2CH_2CH_3OH$	60	97
$CH_2CH_2CH_2CH=CH_2$	70	30
$CH_2CH_2CH_2CH_3OH$	74	117

5.1 Consider the boiling points of the four alkenes in the table above.
  5.1.1 Describe the trend in their boiling points.
  5.1.2 Explain the trend in Question 5.1.1 completely.

5.2 The boiling points of each alcohol is much higher than that of the alkene with a comparable relative mass. Explain this observation by referring to the type and strength of the intermolecular forces in the alkenes and alcohols.

5.3 Consider the boiling points of the four alcohols in the table above.
  5.3.1 Describe the trend in their boiling points.
  5.3.2 Explain the trend in Question 5.3.1 completely.

Answer

5.1 5.1.1 Boiling point increases from ethene to pent-1-ene.

5.1.2 • Chain length (relative molecular mass / molecular size / surface area) increases from ethene to pent-1-ene
  • Strength of the **London forces** (induced dipole forces) increases from ethene to pent-1-ene.
  • More energy is required to overcome intermolecular forces in ethene than in pent-1-ene.

5.2 Between alcohol molecules are strong **hydrogen bonds** in addition to dipole-dipole forces and weak London forces(induced dipole forces).

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5.3 5.3.1 Boiling point increases from methanol to butan-1-ol.

5.3.2 • Chain length (relative molecular mass/molecular size/surface area/alkyl part) increases from methanol to butan-1-ol.

• Strength of the **London forces** (induced dipole forces) increase from methanol to butan-1-ol. (Remember: *The OH-functional group remains the same and thus the hydrogen bonds and dipole-dipole forces remain the same for all four alcohol molecules and is of less importance and the London Forces (induced dipole forces) become stronger as the carbon chain increases in length.*)

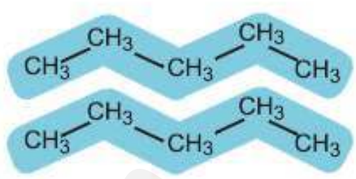
• More energy is required to overcome intermolecular forces in ethene than in pent-1-ene.

4 RELATIONSHIP BETWEEN MELTING POINT, BOILING POINT, VAPOR PRESSURE AND BRANCHED CHAINS

4.1 Boiling point and vapor pressure of branched chains - the liquid state

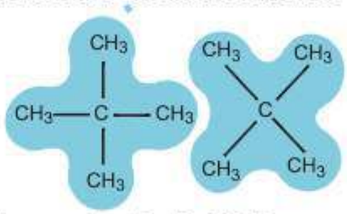
- Straight chain molecules have greater contact surfaces in contact with each other and can be much closer to each other with more points of contact to form intermolecular forces (stronger **London forces** or induced dipole forces) than branched chain molecules.
- Branched chains form more spherical molecules with fewer points of contact for intermolecular forces (weaker **London forces** or induced dipole forces).
- The **boiling points** of branched chain molecules are **lower** than those of straight chain molecules with the same number of C-atoms or molecular mass.

Straight chain molecules



Larger contact areas with stronger forces of attraction.

Branched chain molecules



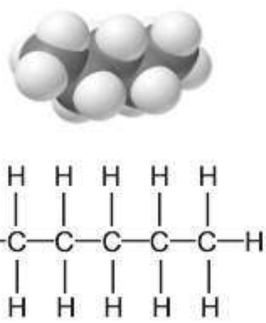
More spherical with fewer points of contact with weaker forces of attraction.

- The **vapor pressure** for branched chain molecules is **higher** than that of straight chain molecules with the same number of C-atoms or molecular mass.

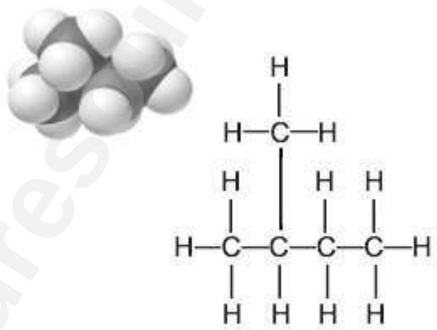
BRANCHED CHAINS

■ **Boiling point and vapor pressure - the liquid state**

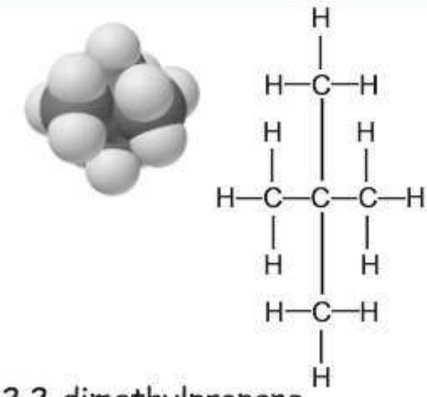
More branches, molecules more compact, more spherical, smaller contact surface



pentane (n-pentane)
molecular mass = 72 g·mol^{-1}
boiling point = 36 °C
vapor pressure = 60 kPa (by 21 °C)
London forces (induced dipole forces)



2-methylbutane
molecular mass = 72 g·mol^{-1}
boiling point = 26 °C
vapor pressure = 79 kPa (by 21 °C)
London forces (induced dipole forces)



2,2-dimethylpropane
molecular mass = 72 g·mol^{-1}
boiling point = 9 °C
vapor pressure = 147 kPa (by 21 °C)
London forces (induced dipole forces)

More branches, size of the contact area over which the intermolecular forces work, decreases

Decrease in strength of London forces (induced dipole forces)
(Intermolecular forces inversely proportional to the number of branches)

- ***Boiling point decreases the more branches occur***
- ***Vapor pressure increases the more branches occur***

Molecular structure : More branches, more spherical with smaller areas over which the intermolecular forces can work
Intermolecular forces :Weaker intermolecular forces
Energy :Less energy is required to overcome (to break) intermolecular forces

- ***Independent*** variable (that is changed): Number of branches in the chain
- ***Dependent variable*** (that is measured): Boiling point or vapor pressure
- ***Controlled variable*** (that remains the same): The same number of C-atoms, comparable molecular mass, same functional group. Same type of homologous series

4.2 Melting points of branched chains - the solid state

Symmetry plays an important role in the **determination of the melting points** of compounds that have the same functional group and the same molecular mass or number of C-atoms, but different shapes. The **more symmetrical and or more spherical** the molecule, the less spaces there are between them and they can pack together more easily in a solid structure (crystal). Multi-branched more symmetrical molecules are usually more spherical with a more compact three-dimensional (3D) structure and their molecules pack together much better in a solid structure than less branched molecules. The tighter the molecules pack together the stronger the intermolecular forces (**stronger London forces** or induced dipole forces) between them in the solid structure the **higher** the **melting point** of the compound.

BRANCHED CHAINS

■ Melting point - the solid state

More branches, symmetry increases, molecules become more symmetrical and most spherical or more compact 3D structure and better pack together into a solid structure (crystal)

less spherical
low melting point



$CH_3–CH_2–CH(CH_3)–CH_3$

2-methylbutane
molecular mass = 72 g·mol^{-1}
melting point = **-160 °C**
London forces (induced dipole forces)

more spherical
high melting point



$C(CH_3)_4$

most spherical

2,2-dimetiehylpropane
molecular mass = 72 g·mol^{-1}
melting point = **-17 °C**
London forces (induced dipole forces)

Increasing symmetry (more symmetrical) and/or most spherical

Increase in strength of London forces (induced dipole forces)

- ***Melting point increases the more symmetrical and/or spherical the molecule is***

Molecular structure: More branches. More symmetrical and/or most spherical. Pack together better in a crystal
Intermolecular forces: Stronger intermolecular forces
Energy: More energy is required to overcome (to break) intermolecular forces

- ***Independent variable*** (that is changed): Increase in symmetry of the molecule
- ***Dependent variable*** (that is measured): Melting point
- ***Controlled variable*** (that remains the same): The same number of C-atoms. Molecular mass. Same functional group. Same type of homologous series

Example 6

The condensed structural formulas, melting and boiling points of three molecules with the molecular formula C_7H_{16} are given below.

Compound	Condensed structure formula	Melting point (°C)	Boiling point (°C)
heptane	$CH_3CH_2CH_2CH_2CH_2CH_3CH_3$	-91	98
2-methylhexane	$CH_3CH(CH_3)CH_2CH_2CH_3CH_3$	-118	90
2,2,3-trimethylbutane	$(CH_3)_3CCH(CH_3)_2$	-26	80

6.1 Why are these compounds ***structural isomers***?
6.2 By comparing the boiling point of 2-methylhexane and 2,2,3-trimethylbutane which of these two compounds have the highest vapor pressure?
Refer to MOLECULAR STRUCTURE, INTERMOLECULAR FORCES and the ENERGY NEEDED to overcome the intermolecular forces to explain the answer.
6.3 Explain the difference in the melting points of the three isomers.

Answer

6.1 Have the same molecular formula but different structural formulas.

6.2 2,2,3-trimethyl butane. Has a lower boiling point than 2-methylhexane.

Structure:

More branched **isomers**. Molecules more spherical. Smaller areas over which the intermolecular forces work.

Intermolecular forces:

Weaker or less intermolecular forces.

Energy:

Less energy is required to overcome intermolecular forces.

6.3 $CH_3CHCH_2CH_2CH_3CH_3$ (with CH_3 branch)

2-methylhexane
Melting point = -118 °C
least symmetrical

$CH_3CH_2CH_2CH_2CH_2CH_3CH_3$

heptane
Melting point = -91 °C
symmetrical

$CH_3C(CH_3)_2CH_2CH_3$

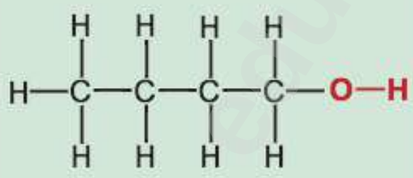
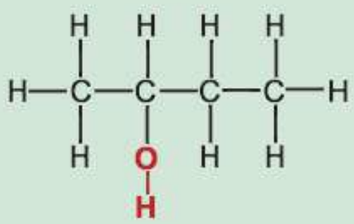
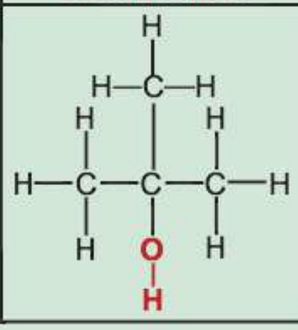
2,2,3-trimethylbutane
Melting point = -26 °C
most spherical
more symmetrical

- 2-methylhexane is the least symmetrical (non-symmetrical). In 2-methylhexane a CH_3 group (branch) is on the main chain which makes packing into the solid (crystal) difficult, thus has a low melting point. Weak London forces (induced dipole forces) between molecules.
- Heptane is symmetrical. The molecules of heptane can be packed somewhat better because they do not have a CH_3 group (branch) on the main chain and the melting point is somewhat higher. It also has the largest surface area and the London forces (induced dipole forces) increase compared with the other two compounds.
- The molecules of 2,2,3-trimethylbutane pack the best in the solid (crystal) because they are the most spherical and the London forces (induced dipole forces) are stronger. More energy is needed to overcome the stronger intermolecular forces. Thus the melting point of 2,2,3-trimethylbutane is the highest.

(**Note**: *The melting points of branched chain alkanes may be higher or lower than the corresponding straight chain alkanes and that depends on the ability of the alkanes to pack in the solid state.*)

Example 7

Consider the three structural isomers of the compound with molecular formula $C_4H_{10}O$.

Compound A	Compound B	Compound C
		

7.1 Which compound **A** or **C** has the lowest boiling point? Give a reason for this difference in boiling points by referring to the strength of intermolecular forces present in each of these compounds.

7.2 Which of **A**, **B** or **C** has the lowest vapor pressure at the same temperature? Refer to their boiling points as reason for the answer.

7.3 Is the boiling point of compound **A** higher or lower than that of pentanal? Explain your answer.

Answer

7.1 **C.** Between alcohol molecules are strong **hydrogen bonds** in addition to dipole-dipole forces and weak London forces (induced dipole forces).

The more branched (more compact) spherical alcohol **C** has the smallest surface area over which the intermolecular forces can work.

In branched substances the **London forces** (induced dipole forces) are weaker because there is less surface area of the atoms exposed to one another.

Decrease in strength of **London forces** (induced dipole forces) lowers the boiling point so that less energy is required to overcome the weaker forces.

(OH-group remains the same and thus hydrogen bonds and dipole-dipole forces remain the same. 2-methylpropan-2-ol is branched and has a more compact spherical shape with a smaller surface area for London forces (induced dipole forces) between their molecules. Butan-1-ol molecules are a straight chain and have a larger surface area in contact with each other for London forces (induced dipole forces). Thus butan-1-ol molecules has stronger London forces (induced dipole forces) between molecules in comparison to 2-methylpropan-2-ol molecules.)

7.2 **A** has the highest boiling point.

7.3 **Higher**. Between the molecules of pentanal are **dipole-dipole forces** in addition to London forces (induced dipole forces).

Between molecules of compound **A** (butan-1-ol) are strong **hydrogen bonds** in addition to dipole-dipole forces and weak London forces (induced dipole forces).
More energy is needed to overcome the hydrogen bonds (intermolecular forces) between molecules of compound **A**.

EXPERIMENT 2

Purpose: Measure and compare the boiling points of various organic substances

Method

1 Measure about 10 ml pentane into a measuring cylinder and pour the pentane into a test tube.
2 Close the test tube with a 2 hole rubber stopper fitted with a thermometer and a glass tube bent at right angles. Connect a rubber tube to one end of the glass tube.
3 Place the other end of the rubber tube that is connected to the glass tube in a basin to keep the flammable vapors away from the Bunsen burner.
4 Make sure the thermometer tip (ball) is about 1 cm above the surface of the liquid, in the test tube. Do not try to move the thermometer through the stopper, it can break. Rather remove the liquid than move the thermometer up or down.
5 Place the 200 ml beaker half filled with water on the ring clamp with mesh.
6 Clamp the test tube to the retort stand. The test tube should be immersed in the beaker with water so that the liquid in the test tube should be below the surface of the water in the beaker, and the tip (ball) of the thermometer must be above the water surface. The thermometer must not touch the inside of the test tube and the test tube must not come into contact with the beaker.



Apparatus set up for Experiment 2.

7 Ignite the Bunsen burner and heat the water slowly.
8 Take the temperature (and record it in the table below) at which the liquid in the test tube boils then remove the burner.
Hint: *Look at the top of the test tube for condensation on the glass tube of the test tube. It means that the liquid is sufficiently boiled to send vapor to the top of the test tube. Take the boiling point reading.*
9 Turn the Bunsen burner off, let the apparatus cool down and then remove the test tube and empty contents into a waste bin.
10 Empty the tap water from the beaker and fill the beaker with fresh tap water.
11 Repeat Steps 1 through 11 for hexane, heptane, ethanol, propan-1-ol and butan-1-ol

Organic liquids required
- pentane (C_5H_{12})
- hexane (C_6H_{14})
- heptane (C_7H_{16})
- ethanol (C_2OH)
- propan-1-ol (C_3OH)
- butan-1-ol (C_4OH)

Apparatus required
- measuring cylinder
- 5 test tubes
- 2 hole rubber stopper
- 200 ml beaker half filled with tap water
- Bunsen burner
- Retort stand
- ring clamp with mesh
- thermometer
- rectangular bent glass tube
- rubber

Safety Measures

- Wear safety glasses.
- Use gloves.
- Avoid contact of skin with chemicals.
- Work in a vapor hood or well-ventilated room.
- Alcohols are flammable - keep away from open flames.
- Be careful when working with the flame of the Bunsen burner - tuck all loose hair away.
- Do not pull or push the thermometer or move the bent glass tube to change their positions. They can easily break if you try to move them.

(OH-group remains the same and thus hydrogen bonds and dipole-dipole forces remain the same. 2-methylpropan-2-ol is branched and has a more compact spherical shape with a smaller surface area for London forces (induced dipole forces) between their molecules. Butan-1-ol molecules are a straight chain and have a larger surface area in contact with each other for London forces (induced dipole forces). Thus butan-1-ol molecules has stronger London forces (induced dipole forces) between molecules in comparison to 2-methylpropan-2-ol molecules.)

7.2 **A** has the highest boiling point.

7.3 **Higher**. Between the molecules of pentanal are **dipole-dipole forces** in addition to London forces (induced dipole forces).

Between molecules of compound **A** (butan-1-ol) are strong **hydrogen bonds** in addition to dipole-dipole forces and weak London forces (induced dipole forces).
More energy is needed to overcome the hydrogen bonds (intermolecular forces) between molecules of compound **A**.

EXPERIMENT 2

Purpose: Measure and compare the boiling points of various organic substances

Method

1 Measure about 10 ml pentane into a measuring cylinder and pour the pentane into a test tube.
2 Close the test tube with a 2 hole rubber stopper fitted with a thermometer and a glass tube bent at right angles. Connect a rubber tube to one end of the glass tube.
3 Place the other end of the rubber tube that is connected to the glass tube in a basin to keep the flammable vapors away from the Bunsen burner.
4 Make sure the thermometer tip (ball) is about 1 cm above the surface of the liquid, in the test tube. Do not try to move the thermometer through the stopper, it can break. Rather remove the liquid than move the thermometer up or down.
5 Place the 200 ml beaker half filled with water on the ring clamp with mesh.
6 Clamp the test tube to the retort stand. The test tube should be immersed in the beaker with water so that the liquid in the test tube should be below the surface of the water in the beaker, and the tip (ball) of the thermometer must be above the water surface. The thermometer must not touch the inside of the test tube and the test tube must not come into contact with the beaker.



Apparatus set up for Experiment 2.

7 Ignite the Bunsen burner and heat the water slowly.
8 Take the temperature (and record it in the table below) at which the liquid in the test tube boils then remove the burner.
Hint: *Look at the top of the test tube for condensation on the glass tube of the test tube. It means that the liquid is sufficiently boiled to send vapor to the top of the test tube. Take the boiling point reading.*
9 Turn the Bunsen burner off, let the apparatus cool down and then remove the test tube and empty contents into a waste bin.
10 Empty the tap water from the beaker and fill the beaker with fresh tap water.
11 Repeat Steps 1 through 11 for hexane, heptane, ethanol, propan-1-ol and butan-1-ol

Organic liquids required
- pentane (C_5H_{12})
- hexane (C_6H_{14})
- heptane (C_7H_{16})
- ethanol (C_2OH)
- propan-1-ol (C_3OH)
- butan-1-ol (C_4OH)

Apparatus required
- measuring cylinder
- 5 test tubes
- 2 hole rubber stopper
- 200 ml beaker half filled with tap water
- Bunsen burner
- Retort stand
- ring clamp with mesh
- thermometer
- rectangular bent glass tube
- rubber

Safety Measures

- Wear safety glasses.
- Use gloves.
- Avoid contact of skin with chemicals.
- Work in a vapor hood or well-ventilated room.
- Alcohols are flammable - keep away from open flames.
- Be careful when working with the flame of the Bunsen burner - tuck all loose hair away.
- Do not pull or push the thermometer or move the bent glass tube to change their positions. They can easily break if you try to move them.

Questions

1. Define the term ***boiling point***.

_____

_____

2. Record the results of this experiment in the following table.

Compound	pentane	hexane	heptane	propan-1-ol	butan-1-ol
Boiling point (°C)					

3. Write an investigative question for this experiment.

_____

_____

4. For this experiment, write down the:

4.1 Independent variable: _____

4.2 Dependent variable: _____

4.3 Controlled variable(s): _____

_____

5. Write down a hypothesis for this experiment.

_____

_____

6. Consider the boiling points of the three alkanes (pentane, hexane and heptane) in this experiment.

6.1 Describe the trend in their boiling points.

_____

6.2 Explain the trend in Question 6.1 fully.

_____

_____

_____

_____

_____

_____

7. The boiling point of propan-1-ol and butan-1-ol is much higher than that of the alkane with a comparable molecular mass. Explain this observation by referring to the type and strength of the intermolecular forces in the alkanes and alcohols.

_____

_____

_____

_____

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8 In experimental studies it was found that the boiling points of the alcohols increase as the molecular size increases. Boiling point of propan-1-ol < butan-1-ol < pentan-1-ol < hexan-1-ol < heptan-1-ol. Explain this tendency fully.

_____

_____

_____

_____

_____

_____

9. Why is this experiment done in a water bath/beaker instead of using direct heating over a flame?

_____

_____

EXPERIMENT 3

Purpose : Measure and compare the vapor pressure of various organic substances

Method

1 Pour cooking oil into a manometer. The levels of the liquid should be the same on both sides of the U-shaped glass tube.
2 Use a rubber tube to connect the manometer to an empty side arm flask of which the pressure on the inside equals the pressure on the outside. The pressure is correct when the oil levels in the U tube are equally high on both sides .
3 Pour a small quantity of pentane into the flask.
4 Place a thermometer in a one hole rubber stopper and seal the bottle with the rubber stopper. Make sure the thermometer is above the surface of the substance in the flask.
5 Place the flask in a water bath, heat the water very slowly.



Apparatus set up for Experiment 3.

6 As the liquid evaporates, the oil begins to rise in the side of the U-tube farthest away from the bottle. The pressure in the bottle forces the oil down on the side nearest to the flask.
7 When the oil stops moving, the vapor pressure equilibrium is reached. The difference between the two levels of the oil in the two sides of the manometer tube is directly proportional to the liquid's vapor pressure.
8 Record oil level difference (in mm) in the manometer in the table below.
9 Repeat Steps 3 to 8 with hexane, heptane, ethanol, propen-1-ol and butan-1-ol.
10 Note the temperature. Vapor pressure differs with the temperature.

Organic liquids needed

- pentane (C_5H_{12})
- hexane (C_6H_{14})
- heptane (C_7H_{16})
- ethanol (C_2OH)
- propan-1-ol (C_3OH)
- butan-1-ol (C_4OH)

Apparatus needed

- manometer (U-shaped glass tube)
- rubber tube
- 1 hole rubber stopper
- thermometer
- side arm flask
- water bath

Questions

1. Define the term ***vapor pressure***.

_____

_____

2. Record the results for this experiment in the following table.

Compound	pentane	hexane	heptane	propan-1-ol	butan-1-ol
Oil level difference in manometer (mm)					

3. Write an investigative question for this experiment.

_____

_____

4. For this experiment, write down the:

4.1 Independent variable: _____

4.2 Dependent variable: _____

4.3 Controlled variable(s): _____

_____

5. Write down a hypothesis for this experiment.

_____

_____

6. Consider the vapor pressure of the three alkanes (pentane, hexane and heptane) in this experiment.

6.1 Describe the trend in their vapor pressure.

_____

6.2 Explain the trend in question 6.1 fully.

_____

_____

_____

_____

_____

_____

7. What conclusion can be drawn from Experiment 2 and Experiment 3 regarding the relation between the intermolecular forces, boiling point and vapor pressure of the alkanes?

_____

_____

_____

_____

8. The vapor pressure of propan-1-ol and butan-1-ol is much lower than that of the alkane with a comparable molecular mass. Explain this observation by referring to the type and strength of the intermolecular forces in the alkanes and alcohols.

_____

_____

_____

_____

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Exercise 10 STRUCTURE AND PHYSICAL PROPERTY RELATIONSHIPS

1. 1.1 Differentiate between **intermolecular** forces and **interatomic** (intramolecular) forces.

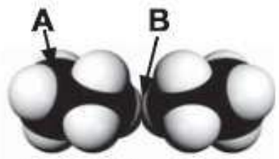
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_____

_____

_____

1.2 What type of forces (intermolecular or interatomic) are represented by A and B in the diagram (of ethane molecules)



A : _____

B : _____

1.3 Which of these forces in question 1.2 above are responsible for the chemical properties of a substance?

_____

1.4 Which of these forces in question 1.2 above are responsible for the physical properties of a substance?

_____

2. Give a brief description of the following intermolecular forces:

2.1 London forces (or induced dipole forces).

_____

2.2 Dipole-dipole forces.

_____

2.3 Hydrogen bonds. _____

_____

3. Complete the following table further, which is summary of the type of intermolecular forces found between the molecules of the same homologous series of compounds.

Homologous Series	Polar or non-polar	Contains a O-H bond	Intermolecular forces between molecules			Soluble in water
			London forces (induced dipole forces	Dipole-dipole-forces	Hydrogen bonds	
Alkanes	✗	✗	✓	✗	✗	
Alkenes						
Alkynes						
Haloalkanes						✗
Aldehydes						
Ketones						
Esters						
Alcohols						✓
Carboxylic acids						

4. For alcohol molecules and carboxylic acid molecules with the same number of C-atoms or corresponding molecular mass, which molecules have the strongest hydrogen bonds between their molecules? Explain your answer.

_____

_____

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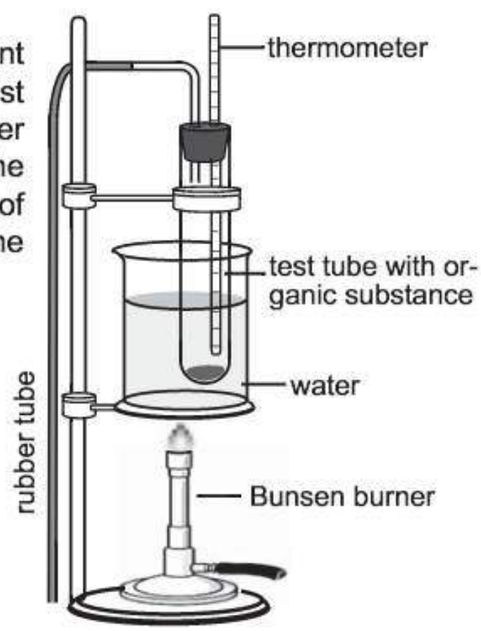
5. Complete the following table to further indicate the relationship between the structure and physical properties for organic molecules.

Relationship	Structure and physical properties
Between melting point, boiling point and vapor pressure and the strength of the intermolecular forces (strength of the polarity of the functional group)	• The more polar the functional group the stronger the intermolecular forces and the higher the boiling and melting points. • The more polar the functional group is the stronger the intermolecular forces and the lower the vapor pressure.
Between the melting point, boiling point and vapor pressure and the number functional groups of the same type	
Between melting point, boiling point and vapor pressure and the chain length	
Between boiling point and vapor pressure and the number of branched chains	
Between melting point, and the number of branched chains	

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6. A student performs an experiment to determine the **boiling points** of different organic substances. He places a small amount of an organic substance in a test tube. He then places the test tube which contains a rubber tube and thermometer in a water bath and heats the water carefully, as shown in the figure. The experiment is repeated with each of the other substances. The boiling point of every substance is read on the thermometer and the results are recorded in the table below.

	Name	Formula	Molecular mass ($g \cdot mol^{-1}$)	Boiling point (°C)
A	Pentan-1-ol	$CH_3(CH_2)_4OH$	88	138
B	Pentanal	$CH_3(CH_2)_3CHO$	88	103
C	Butanoic acid	$CH_3(CH_2)_2CO_2H$	88	164
D	Ethyl ethanoate	$CH_3CO_2C_2H_5$	88	77
E	Hexane	$CH_3(CH_2)_4CH_3$	88	69



Apparatus set up to test boiling points.

6.1 Define the term ***boiling point***.

_____

_____

6.2 Provide an investigative question for this experiment.

_____

_____

6.3 For this experiment give the:

6.3.1 Independent variable: _____

6.3.2 Dependent variable: _____

6.4 Why must the molecular mass of each compound be kept the same during this experiment?

_____

_____

6.5 What is the purpose of the rubber tube that is connected to the test tube?

_____

_____

_____

6.6 To which homologous series do the following belong?

6.6.1 Compound **A**? _____ 6.6.2 Compound **B**? _____

6.6.3 Compound **C**? _____ 6.6.4 Compound **D**? _____

6.6.5 Compound **E**? _____

6.7 Explain the difference in the boiling points of **D** and **E**. Refer to the type and strength of intermolecular forces and energy in your answer.

_____

_____

_____

_____

_____

_____

6.8 Draw the structural formulas of compounds **A**, **C** and **E**.

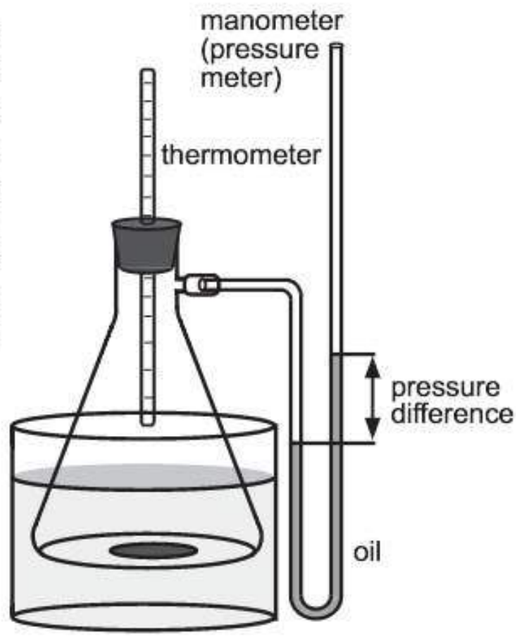
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6.9 Explain the difference in the boiling points of **A**, **C** and **E**. Refer to the type and strength of the intermolecular forces and energy in your answer.

6.10 Arrange these compounds in order of increasing vapor pressure. Write down the letter of the compounds.

6.11 Give a reason for your arrangement in Question 6.10 by referring to the boiling point of the compounds.

7. Cindy performs an experiment to determine which properties of organic compounds affect the **vapor pressure**. She uses a manometer and performs the experiment. The apparatus is shown on the right. She places small amounts of each of the organic substances in the flask. She places the flask, which is sealed, in a water bath that contains hot water. Some of the organic substances evaporate and pushes the level of the oil down in the manometer. The change in the level of the oil in the manometer is an indication of the vapor pressure of the substance. She uses the compounds in the table given below. The vapor pressure of each substance is read (pressure difference) from the manometer and are recorded in the table below.



Apparatus set up to measure vapor pressure .

	Compound	Level difference in manometer (mm)
A	pentane	400
B	hexane	100
C	heptane	40
D	octane	10
E	2-methylbutane	450
F	butan-2-one	15
G	butan-2-ol	12
H	propanoic acid	2

7.1 Define the term ***vapor pressure***.

7.2 Give a suitable investigative question for this experiment.

7.3 For the investigation, name the:

7.3.1 Independent variable: _____

7.3.1 Dependent variable: _____

7.4 Write down TWO factors that should be kept constant for this investigation.

_____

_____

7.5 Describe the trend in vapor pressure of compounds A to D.

_____

_____

7.6 Refer to MOLECULAR STRUCTURE, INTERMOLECULAR FORCES and the ENERGY NEEDED to overcome the intermolecular forces, to explain the answer to Question 7.5.

_____

_____

_____

_____

_____

_____

7.7 Pentane and 2-methylbutane are ***structural isomers***. Why are they structural isomers?

_____

7.8 The vapor pressure of 2-methylbutane is much higher than that of pentane with the same molecular mass. Explain this observation by referring to the structure (isomers), type and strength of intermolecular forces of these two compounds.

_____

_____

_____

_____

_____

_____

_____

7.9 The vapor pressure of propanoic acid is lower than that of butan-2-ol, which in turn is much lower than that of butan-2-one. Explain this observation by referring to the type and strength of the intermolecular forces in ketones, alcohols and carboxylic acids.

_____

_____

_____

_____

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7.10 Give a conclusion which can be derived from the results of this experiment.

8. A practical investigation is carried out to determine boiling points of the compounds A to E, which contains different functional groups and compare them. The results are recorded in a table.

	Condensed formula	Relative molecular mass	Boiling punt (°C)
A	$CH_3(CH_2)_2CO_2H$	88	164
B	$CH_3CH_2CO_2CH_3$	88	80
C	$CH_3CO_2C_2H_5$	88	77
D	$CH_3(CH_2)_3CHO$	88	103
E	$CH_3(CH_2)_3COCH_3$	88	102
F	$CH_3(CH_2)_4OH$	88	138
G	$CH_3(CH_2)_4CH_3$	88	69

8.1 What other variable is controlled during this investigation (except conditions for determining boiling points)?

8.2 Formulate an investigative question for this investigation.

8.3 Complete the following table to indicate to which homologous series each of these compounds belong and the type of intermolecular forces between their molecules.

	Condensed formula	Homologous series	Intermolecular forces between molecules			Dominating (main) intermolecular forces
			London forces (Induced dipole forces	Dipole-dipole-forces	Hydrogen-bonds	
A	$CH_3(CH_2)_2CO_2H$					
B	$CH_3CH_2CO_2CH_3$					
C	$CH_3CO_2C_2H_5$					
D	$CH_3(CH_2)_3CHO$		✓	✓	✗	
E	$CH_3(CH_2)_3COCH_3$					
F	$CH_3(CH_2)_4OH$					1 × Hydrogen bond
G	$CH_3(CH_2)_4CH_3$	Alkanes				

8.4 To which homologous series would the compound with the highest boiling point belong. Give a reason for the high boiling point by referring to the type and strength of the intermolecular forces between their molecules.

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8.5 Which compound has the highest vapor pressure? Refer to the boiling point and strength of the intermolecular forces of this compound.

9. A laboratory technician is provided with three unmarked bottles, respectively; an alcohol, an aldehyde and an alkane with similar molecular mass. She takes a sample from each bottle and labels them **P**, **Q** and **R**. To identify each compound, she determines the boiling point of each under the same conditions. The results are in the table below.

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

9.1 For the investigation, name the:

9.1.1 Independent variable:

9.1.2 Dependent variable:

9.2 Design an investigation that the laboratory technician can perform. Use the following headings in your design.

9.2.1 Hypothesis:

9.2.2 Precautions:

9.2.3 Apparatus:

9.2.4 Method:

9.3 From the passage, write the phrase that indicates that this investigation is a fair test.

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9.4 Which compound **p**,**q** or **r**, is an:

9.4.1 Alkane: _____ 9.4.2 Alcohol: _____

9.4.3 Refer to the boiling points and the type of intermolecular forces present between alcohol molecules as a reason for your answer to QUESTION 9.4.2.

_____

_____

_____

_____

10. Three bottles respectively containing propanol, propan-1,2-diol and propan-1,2,3-triol.



The condensed structure formula and vapor pressure of each of these compounds are as follows:

	Compound	Condensed formula	Vapor pressure (kPa at 20°C)
Bottle 1	Propanol	$CH_3CH_2CH_2$**OH**	2,66
Bottle 2	Propan-1,2-diol	CH_2**OH**CH**OH**CH_3	1,07
Bottle 3	Propan-1,2,3-triol	CH_2**OH**CH**OH**CH_2**OH**	0,002

10.1 In the sketches of the bottles above, use dots (•) to indicate the difference in vapor pressure in the three bottles.

10.2 Define the term ***vapor pressure***. _____

_____

10.3 Write down the homologous series to which these three compounds belong. _____

10.4 State the type of intermolecular forces which occur between the molecules of these compounds.

_____

10.5 Which of the intermolecular forces named in Question 10.4 are the dominant (main) intermolecular forces responsible for the difference in vapor pressure between these three compounds?

_____

10.6 Consider the vapor pressure of these three compounds and describe the trend in their vapor pressure.

_____

_____

10.7 Now use your answer to Question 10.5 and explain the trend stated in Question 10.6 above in full.

_____

_____

_____

_____

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10.8 Which one of these three compounds has the highest boiling point? Explain your answer.

11. The table below shows the melting and boiling points of two different alcohols **A** and **B**.

	Compound	Condensed formula	Melting point (°C)	Boiling point (°C)
A	butan-1,4-diol	CH_2**OH**$CH_2CH_2CH_2$**OH**	-90	118
B	butan-1,2,3,4-tetrol	CH_2**OH**CH**OH**CH**OH**CH_2**OH**	90	330

11.1 What is the state (gas, liquid or solid) of each of these alcohols A and B at room temperature?

A : _____ **B** : _____

11.2 Draw the structural formulas for each of the alcohols **A** and **B**.

11.3 Explain why the melting and boiling points of the two alcohols increase in the order from **A** to **B**.

11.4 What trend in boiling points can be observed from the graph?

11.5 How will the vapor pressure of alcohol **A** compare with that of alcohol **B**? Write HIGHER THAN, LOWER THAN or EQUAL TO. Refer to MOLECULAR STRUCTURE, INTERMOLECULAR FORCES and the ENERGY NEEDED to overcome the intermolecular forces, to explain the answer.

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12. The following two tables can be used to compare some of the boiling points of haloalkanes

TABLE 1		
Haloalkane	**Formula**	**Boiling points (°C)**
fluoromethane	CH_3F	194,7
chloromethane	$CH_3C\ell$	248,9
bromomethane	CH_3Br	276,7
Iodomethane	CH_3I	315,5

TABLE 2		
Haloalkane	**Formula**	**Boiling points (°C)**
chloromethane	$CH_3C\ell$	-24,1
dichloromethane	$CH_2C\ell_2$	40,1
trichloromethane	$CHC\ell_3$	61,8
tertrachloromethane	CCl_4	76,6

Use the information given in the tables above to answer the following questions:

12.1 Write down the FORMULA of **two** haloalkanes you think would be the most dangerous at 25 ° C. Give a reason for your answer.

12.2 Describe the trend in the boiling points as illustrated in Table 1 and give an explanation for this trend.

12.3 Predict the relationship between the number of chlorine atoms and the boiling point as illustrated in Table 2. Suggest what should be kept constant.

13. The table shows the boiling points of five alkanes and their corresponding alkenes and alkynes. All the molecules have unbranched chains.

Alkane	Boiling point (°C)	Alkene	Boiling point (°C)	Alkyne	Boiling point (°C)
ethane	-89	ethene	-169	ethyne	-84
propane	-42	propene	-48	propyne	-23
butane	-0,5	but-1-ene	-6	but-1-yne	8
pentane	36	pent-1-ene	30	pent-1-yne	40
hexane	69	hex-1-ene	84	hex-1-yne	71

13.1 Classify the alkanes as saturated or unsaturated hydrocarbons? Give a reason for your answer.

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13.2 Why are alkenes and alkynes classified as unsaturated hydrocarbons?

13.3 Name the type of molecular forces which occur between the molecules of these compounds (alkanes, alkenes and alkynes).

13.4 Consider the boiling points of alkanes, alkenes and alkynes in the table at the bottom of the previous page.

13.4.1 Describe the trend in their boiling points, as from the top to the bottom of the table.

13.4.2 Explain the trend in QUESTION 13.4.1.

13.5 Place the alkanes, alkenes and alkynes in decreasing order of strength of intermolecular forces.

14. The table shows the boiling points of the first six alkanes and the first six alcohols in their corresponding series. All the molecules have branched chains.

Alkane	Boiling Point (°C)	Alcohols	Boiling Point (°C)
methane	-164	methanol	65
ethane	-89	ethanol	78
propane	-42	propan-1-ol	98
butane	-0,5	butan-1-ol	117
pentane	36	pentan-1-ol	138
hexane	69	hexan-1-ol	156

14.1 Define the term ***boiling point***.

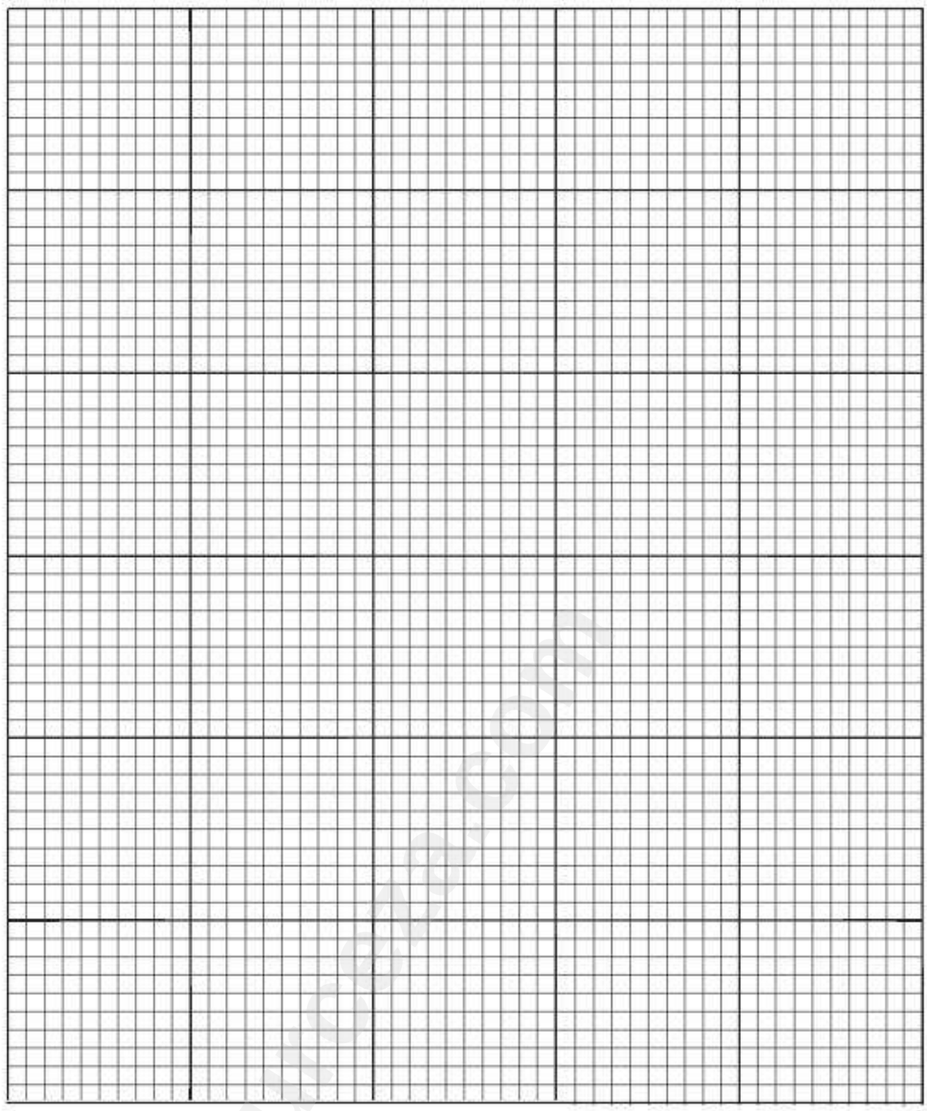
14.2 Consider the boiling point of the six alkanes in the table above.

14.2.1 Describe the trend in their boiling points.

14.2.2 Explain the trend in QUESTION 14.2.1 fully.

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14.3 Draw a graph of boiling points versus the number of C-atoms of the first six ALCOHOLS. Select 50 °C and one C-atom as the origin and use an appropriate scale. Plot the points and draw the most suitable curve through the points



14.4 What trend in boiling points can be observed from the graph?

_____

14.5 Give a reason for the trend mentioned in QUESTION 14.4 by referring to the type of intermolecular forces.

_____

_____

_____

14.6 Explain by referring to the type of intermolecular forces, why the boiling points of the alcohols are higher than the boiling points of the alkanes.

_____

_____

_____

14.7 People are always warned to keep liquids such as gasoline (a mixture of alkanes) out of reach of children. Use the boiling points of the alkanes and justify this precaution.

_____

_____

14.8 Explain briefly why ethanol is a renewable energy source, while alkanes are non-renewable.

_____

_____

_____

14.9 Will the vapor pressure of the alcohols increase or decrease if the number of C-atoms in the chain increases? Give a reason for your answer.

_____

_____

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

Hydrocarbons	Vapor pressure (mmHg)
A	450
B	592
C	1 102

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

_____

15.2 Write the following for this investigation.

15.2.1 Dependent variable: _____

15.2.2 Independent variable: _____

15.2.3 Controlled variable(s): _____

15.3 Are these hydrocarbons saturated or unsaturated? Explain your answer.

_____

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

15.4.1 The letter (**A**, **B** or **C**) that represents this hydrocarbon. _____

15.4.2 It's IUPAC-name. _____

15.5 Consider hydrocarbon **C** and its vapor pressure.

15.5.1 Write the structural formula of hydrocarbon **C**.

15.5.2 Explain why hydrocarbon **C** has the highest vapor pressure. In your explanation, refer to its MOLECULAR STRUCTURE, INTERMOLECULAR FORCES and the ENERGY required.

_____

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

15.7 Give a reason why branched hydrocarbons are chosen to use as fuel rather than straight chain carbons.

16. Study the trend of the melting and boiling points of four isomers of C_6H_{14}.

	Isomers of C_6H_{14}	Melting point (°C)	Boiling point(°C)
A	$CH_3—CH_2—CH_2—CH_2—CH_2—CH_3$	-95	69
B	$CH_3—CH(CH_3)—CH_2—CH_2—CH_3$	-145	63
C	$CH_3—CH(CH_3)—CH(CH_3)—CH_3$	-135	58
D	$CH_3—C(CH_3)_2—CH_2—CH_3$	-98	50

16.1 Define the term **isomers**.

16.2 What are the molecular formulae for the above mentioned isomers?

16.3 What type of structure isomers are these compounds classified as? Give a reason for your answer.

16.4 Describe the trend in the **boiling points** of the compounds in the table.

16.5 Give an explanation for your answer to Question 16.4.

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16.6 Compounds **C** and **D** have the same number of branches, but their **boiling points** differ considerably. Give a reason for this.

16.7 Define the term ***melting point***.

16.8 Explain with reasons the variation in **melting points** of compounds **A**, **B** and **D**.

17. Consider the following compounds which belong to different homologous series.

	A	B	C	D
Compound	$CH_3CH_2CH_3$	CH_3CHO	CH_3COOH	CH_3CH_2OH

17.1 Define the concept ***homologous series***.

17.2 Name the homologous series to which compounds **A** and **C** belongs.

A : _____ **C** : _____

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17.3 Give the IUPAC-name of compounds **B** and **D**.

B : _____ **D** : _____

17.4 Arrange these four compounds in order of increasing boiling points. Give a reason for the order.

_____

_____

_____

_____

_____

_____

_____

_____

_____

18. Arrange the following compounds in each group according to increasing boiling points. Give a reason for the order.

For example:

$CH_3CH_2CH_2CH_2CH_3$	$CH_3CH_2CH_2CH_2OH$	$CH_3CH_2CH_2CH_2Br$	$CH_3CH_2CH_2CH_2CH_2OH$

Answer:

Increasing boiling point →

$CH_3CH_2CH_2CH_2CH_3 < CH_3CH_2CH_2CH_2Br < CH_3CH_2CH_2CH_2OH < CH_3CH_2CH_2CH_2CH_2OH$

London forces (induced dipole forces)	London forces (induced dipole forces) Dipole-dipole forces	London forces (induced dipole forces) Dipole-dipole forces	London forces (induced dipole forces) Dipole-dipole forces Hydrogen bonds Greater contact surface

18.1

$CH_3(CH_2)_4I$	$CH_3(CH_2)_6I$	$CH_3(CH_2)_7I$	$CH_3(CH_2)_5I$

18.2

$CH_3CH_2CH_2CH_2CH_2CH_2CH_3$	$CH_3CH_2CH(CH_3)CH_2CH_2CH_3$	$CH_3C(CH_3)_2CH_2CH_2CH_3$

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18.3

$CH_3CH_2CH_2I$	$CH_3CH_2CH_2C\ell$	$CH_3CH_2CH_2F$

18.4

$(CH_3)_3CBr$	$CH_3CH_2CH_2CH_2Br$

18.5

$CH_3CH_2C(CH_3)_2OH$	$CH_3CH_2CH_2CH_2CH_2OH$	$CH_3CHOHCH_2CH_3$

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19. Arrange the following compounds in each group according to increasing melting points. Give a reason for the order (Use the method in question 18).

19.1

$CH_3CH_2CH_2CH_2CH_2CH_2CH_3$	$CH_3CH_2CH(CH_3)CH_2CH_2CH_3$	$CH_3C(CH_3)_2CH_2CH_2CH_3$

19.2

$CH_3CH_2CH_2CH_2CH_2OH$	$(CH_3)_3COH$	$(CH_3)_2CHCH_2OH$

20. There are two structural isomers of organic compounds with molecular formula $C_2H_4O_2$.

20.1 Define the term *structural isomer*.

_____

_____

20.2 Write the structural formulas of these two isomers and next to each the IUPAC name thereof.

20.3 What type of structural isomers are these compounds classified as? Give a reason for your answer.

_____

_____

20.4 State with reason which ONE of these isomers

20.2.1 Have a higher boiling point.

_____

_____

_____

20.2.2 Have a higher vapor pressure.

_____

_____

_____

20.5 Would the vapor pressure of the carboxylic acids increase or decrease if the number of C-atoms in the chain increases? Give a reason for your answer.

_____

_____

_____

21. The table below shows the boiling points of two organic compounds, indicated by the letters **A** and **B**.

Compound		Molecular mass	Boiling point (°C)
A	Butane	58	0
B	Propanal	58	49

21.1 Is compound **A** in the GAS-, LIQUID- or SOLID state at 25 °C? _____

21.2 Compound **A** has a lower boiling point than compound **B,** give reasons for this variation in boiling points, according to the following aspects: Structural differences between the two compounds and polarity.

_____

_____

_____

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APPLICATIONS OF ORGANIC CHEMISTRY

COMBUSTION AND ESTERIFICATION REACTIONS

Organic chemistry can undergo a wide range of chemical reactions which we encounter every day. We are now going to study two of these reactions.

COMBUSTION IN AIR

Over millions of years the remains of dead animals and decomposed plant and animal material are changed into fossil fuels such as coal, crude oil and natural gas. The solar energy originally stored in these compounds are being released again at combustion. When we use gasoline, which is one of the products of refined crude oil, in a car engine, or gas for cooking or coal to produce electricity, the fuel reacts with oxygen.

Alkanes are the main component of fossil fuels.

In an ideal reaction the products of the combustion of gasoline and coal in oxygen would only be water and carbon dioxide, but because gasoline and coal are not pure or clean, there are sometimes by-products such as mercury, arsenic and sulphur. Combustion of sulphur found in these fuels produces toxic sulphur dioxide (SO_2). Insufficient combustion has carbon as a by-product in the form of soot.

Short chain alkanes have similar molecules that easily burn and produce the best fuels. The combustion of alkanes are highly exothermic and carbon dioxide and water are produced. The general reaction for the combustion of alkanes are:

$$\text{alkane} + O_2 \rightarrow CO_2 + H_2O \qquad \Delta H < 0$$

Examples:

A mixture of propane and butane gas, highly pressurised, is a liquid. This liquid is found in the cylinders of camp stoves and laboratory gas bottles.

(1) Write the balanced equation for propane when burning in excess oxygen.

(2) Write the balanced equation for butane when burning in excess oxygen.

Answer:

(1) Use the general formula for alkanes, C_nH_{2n+2}, to obtain the molecular formula of propane.

Propane has 3 **C**-atoms with molecular formula: $C_3H_{2(3)+2} = C_3H_8$.

When an alkane burns in sufficient oxygen (O_2), carbon dioxide (CO_2) and water (H_2O) forms.

The unbalanced chemical equation for the complete combustion of propane in oxygen is:

$$C_3H_8 + O_2 \rightarrow CO_2 + H_2O$$

Now follow the following steps to balance the equation:

Step 1 : *Balance the* **C***-atoms.*

$$C_3H_8 + O_2 \rightarrow CO_2 + H_2O$$

Left: **C** = 3 Right: **C** = 1

There are 3 **C**-atoms on the left side and 1 **C**-atom on the right. Place a "**3**" in front of CO_2 on the right hand side.

$$C_3H_8 + O_2 \rightarrow 3CO_2 + H_2O$$

The **C**-atoms are now balanced.

Step 2 : *Balance the* **H***-atoms.*

$$C_3H_8 + O_2 \rightarrow 3CO_2 + H_2O$$

Left: **H** = 8 Right: **H** = 2

There are 8 **H**-atoms on the left side and 2 **H**-atoms on the right. Place a "**4**" in front of H_2O on the right hand side.

$$C_3H_8 + O_2 \rightarrow 3CO_2 + 4H_2O$$

The **H**-atoms are now balanced.

Step 3 : *Balance the* **O***-atoms.*

$$C_3H_8 + O_2 \rightarrow 3CO_2 + 4H_2O$$

Left: **O** = 2 Right: **O** = 3(2) + 4(1) = 6 + 4 = 10

There are 2 **O**-atoms on the left side and 10 **O**-atoms on the right. Place a "**5**" in front of O_2 on the left hand side.

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

The **O**-atoms are now balanced.

The balanced equation for the combustion reaction of propane is:

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

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(2) Butane has 4 C-atoms with molecular formula: $C_4H_{2(4)+2} = C_3H_{10}$.

The unbalanced chemical equation for the complete combustion of butane in oxygen is:

$$C_4H_{10} + O_2 \rightarrow CO_2 + H_2O$$

Step 1 : *Balance the C-atoms.*

$$C_4H_{10} + O_2 \rightarrow CO_2 + H_2O$$

Left: C = 4 Right: C = 1

There are 4 C-atoms on the left side and 1 C-atom on the right. Place a "4" before CO_2 on the right hand side.

$$C_4H_{10} + O_2 \rightarrow 4CO_2 + H_2O$$

The C-atoms are now balanced.

Step 2 : *Balance the H-atoms.*

$$C_4H_{10} + O_2 \rightarrow 4CO_2 + H_2O$$

Left: H = 10 Right: H = 2

There are 10 H-atoms on the left side and 2 H-atom on the right. Place a "5" before H_2O on the right hand side.

$$C_4H_{10} + O_2 \rightarrow 4CO_2 + 5H_2O$$

The H-atoms are now balanced.

Step 3 : *Balance the O-atoms.*

$$C_4H_{10} + O_2 \rightarrow 4CO_2 + 5H_2O$$

Left: O = 2 Right: O = 4(2) + 5(1) = 8 + 5 = 13

There are 2 O-atoms on the left side and 13 O-atoms on the right. Place a "6½" before CO_2 on the right hand side.

$$C_4H_{10} + 6\frac{1}{2}O_2 \rightarrow 4CO_2 + 5H_2O$$

The O-atoms are now balanced.

To ensure that there are no fractions in the final balanced equation, multiply the number in front of each formula with 2.

The balanced equation for the combustion reaction for butane is:

$$2C_4H_{10} + 13O_2 \rightarrow 8CO_2 + 10H_2O$$

ESTERIFICATION

A **Ester** (**RCOOR'**) is an organic compound that is formed in a reaction between a **carboxylic acid** (**RCOOH**) and an **alcohol** (**R'OH**) in the presence of a catalyst, H_2SO_4, when heated. The process (reaction) is known as **acid-catalyzed condensation** or **esterification**. In the reaction, water is eliminated (extracted) and forms the product with an ester. The formulated water (H_2O) is obtained by removing the **-OH** from the carboxylic acid and an **-H** which the alcohol loses. (*a condensation reaction is one in which water or other small molecules are eliminated*).



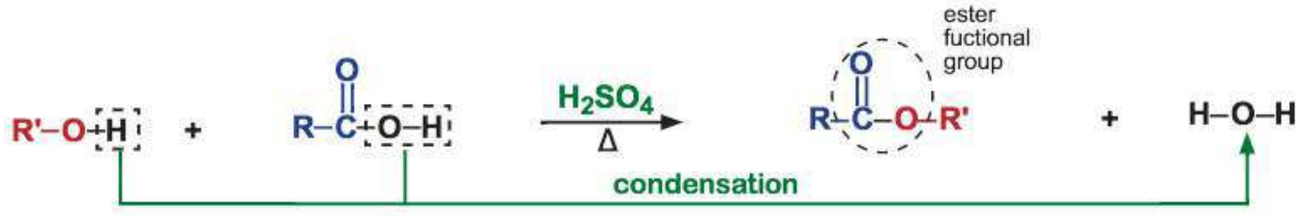
Natural esters occurs in fruit.

Esters have pleasant, distinctive smells and occur freely in nature in fruits and flowers.

The general equation for esterification reactions are:

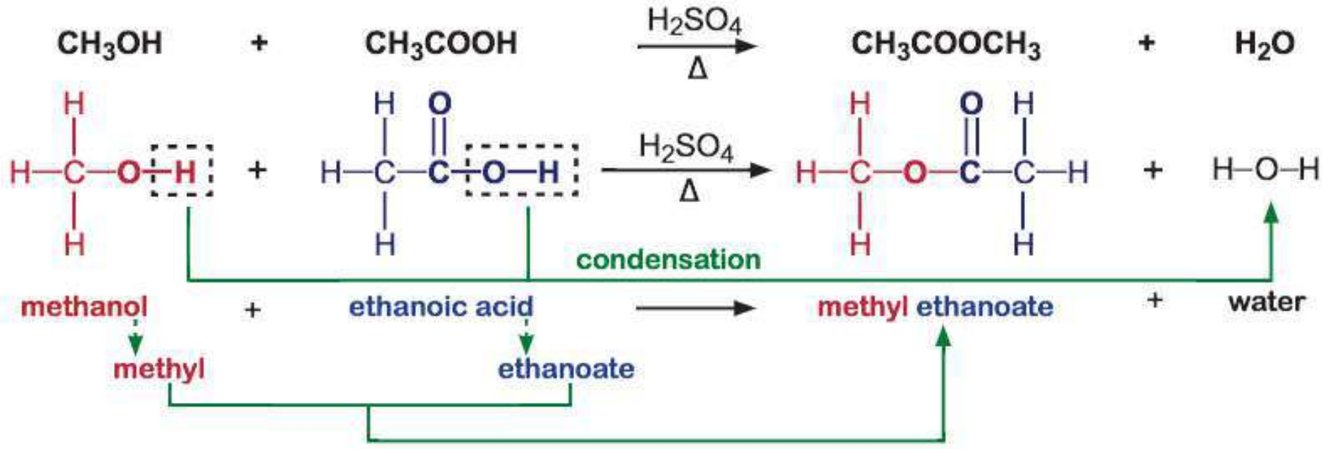
$$R'OH + RCOOH \xrightarrow[\Delta]{H_2SO_4} RCOOR' + H_2O$$

Alcohol + Carboxylic acid $\xrightarrow[\Delta]{H_2SO_4}$ Alkylalkanoate (ester) + water



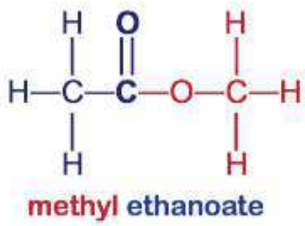
Let's look at some examples by utilizing structure formulae to write a balanced equation for the esterification reaction that occurs between an alcohol and a carboxylic acid in the presence of a catalyst.

(1) Use structural formulas and give the balanced chemical equation for the esterification reaction that occurs between methanol and ethanoic acid in the presence of sulphuric acid.

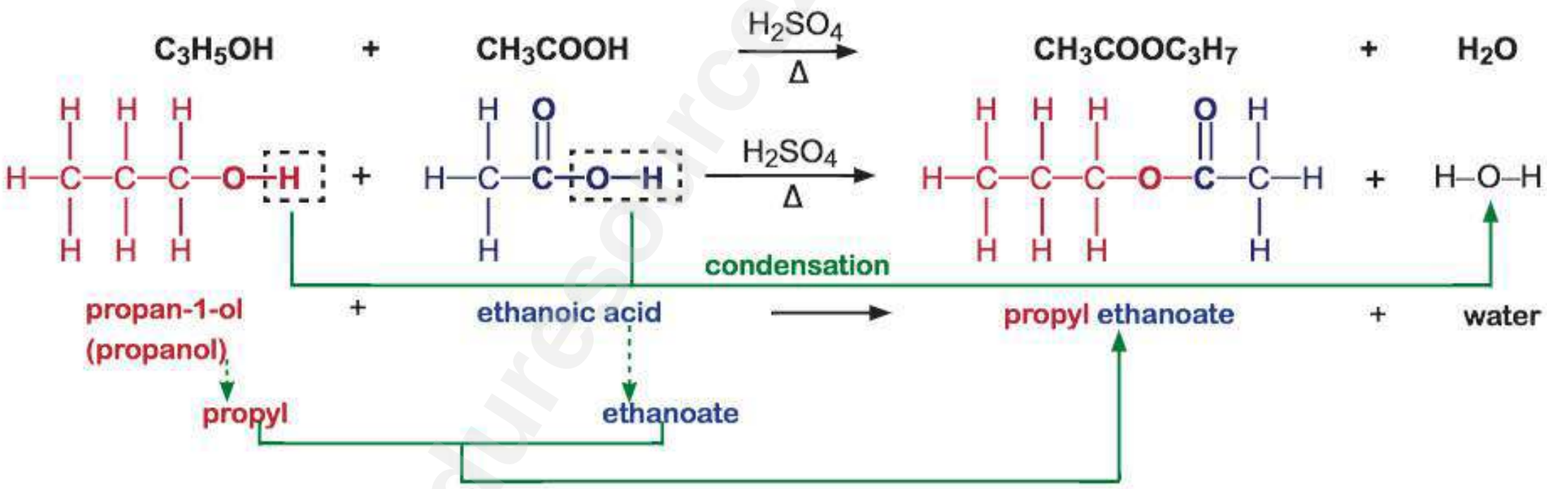


Remember, the first part of an ester is named after the alcohol part (methanol → methyl, ethyl → ethanol, propanol → propyl, etc.) and the second part named after the carboxylic acid part (methanoic acid → methanoate, ethanoic acid → ethanoate, propanoic acid → propanoate, etc.).

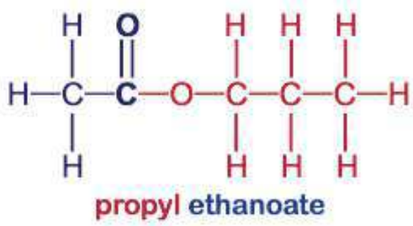
Methyl ethanoate can also be drawn with the carboxylic acid structure followed by the alcohol structure.



(2) Use structural formulas and give the balanced chemical equation for the esterification reaction that takes place between propan-1-ol and ethanoic acid in the presence of sulphuric acid.



Propyl ethanoate can also be drawn with the carboxylic acid structure followed by the alcohol structure.

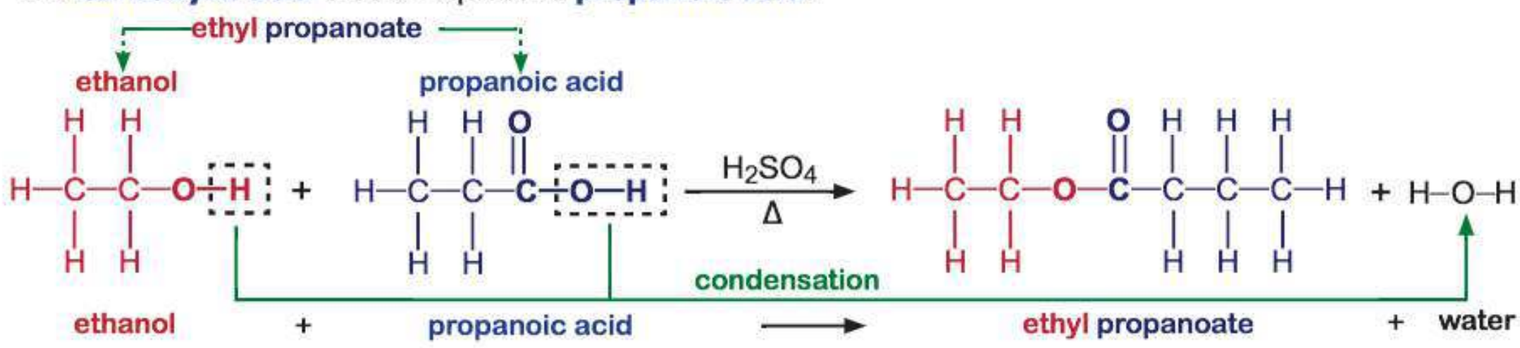


(3) Use structural formulas and give the balanced equation for the production of ethyl propanoate.

- In this case it is necessary to determine the reactants needed to produce ethyl propanoate.

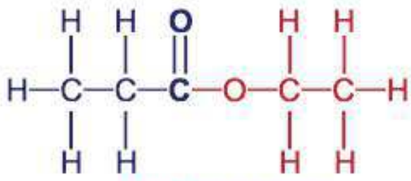
The **alcohol** that is required is **ethanol**.

The **carboxylic acid** that is required is **propanoic acid**.



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Ethyl propanoate can also be drawn with the carboxylic acid structure followed by the alcohol structure.



etielpropanoate

EXPERIMENT 4

Purpose : Synthesis and identification of esters

Method

1. Number the test tubes 1 to 6 and place them in a test tube holder.
2. Add the right amount of the substances into the test tubes as indicated in the table.

Test tube	Carboxylic acid	Alcohol
1	1 cm^3 ethanoic acid	1 cm^3 methanol
2	1 cm^3 ethanoic acid	1 cm^3 ethanol
3	1 cm^3 ethanoic acid	1 cm^3 pentan-1-ol
4	1 cm^3 salicylic acid	1 cm^3 methanol
5	1 cm^3 salicylic acid	1 cm^3 ethanol
6	1 cm^3 salicylic acid	1 cm^3 pentan-1-ol



Apparatus set up for Experiment 4.

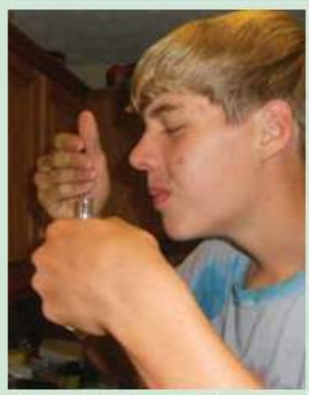
3. Carefully add four drops of concentrated sulfuric acid into each test tube.
4. Place a beaker with water on the gauze on a tripod.
5. Place the first test tube (test tube **1**) in the beaker with water and heat for approximately 6 minutes. The water should be heated to a temperature of about 75 °C.
6. Remove the test tube with a test tube clamp from the beaker and cool the test tube in a cup of cold water or under running tap water.
7. After it has cooled, add 5 ml of distilled water to the test tube. Hold the test tube about 30 cm from the nose and wave the fumes towards you with your hand and smell the ester. Record your observation in the table below.
8. Repeat steps 4 to 7 for each of the test tubes **2** to **6** for the different combinations of an alcohol and a carboxylic acid.
9. Wash your hands thoroughly after the experiment.
10. Dilute the product with plenty of water before it is rinsed out into the gutter.

Organic liquids needed

- methanol (CH_4O)
- ethanol (C_2H_6O)
- pentan-1-ol ($C_5H_{12}O$)
- ethanoic acid ($C_2H_4O_2$)
- salicylic acid ($C_7H_6O_3$)
- concentrated sulfuric acid (H_2SO_4)

Equipment required

- measuring cylinder
- medicine dropper
- three test tubes
- glass beaker with water
- thermometer
- bunsen burner
- test tube holder
- test tube clamp
- tripod with gauze
- marker



Wave the fumes towards you with your hand.

Safety Measures

- Wear safety glasses and use gloves.
- Avoid contact of chemicals with skin.
- Sulphuric acid is corrosive and can cause burns.
- Organic acids can be irritating to the skin and eyes.
- Work in a vapor hood or well-ventilated room.
- Alcohols are flammable - keep away from open flames

Questions

1. Complete the following table:

Test tube	Carboxylic Acid	Alcohol	Name of ester	Smell
1	ethanoic acid	methanol		
2	ethanoic acid	ethanol		
3	ethanoic acid	pantan-1-ol		
4	salicylic acid	methanol		
5	salicylic acid	ethanol		
6	salicylic acid	pantan-1-ol		

2. What is the use of adding concentrated sulfuric acid to each of the reaction mixtures?

_____

3. Write down a common equation for the preparation of esters.

_____

4. Use structural formulas and write down an equation for the reaction that took place in:
   4.1 **Test tube 1**

   4.2 **Test tube 2**

   4.2 **Test tube 3**

5. Complete the following table:

Alcohol	Carboxylic acid	Name of ester	Smell
Ethanol	Butanoic acid		Apricot
Octan-1-ol		Octyl ethanoate	Orange
	Methanoic acid	Ethyl methanoate	Rum
Butan-1-ol	Butanoic acid		Pineappel

6. Why are esterification reactions also sometimes referred to as condensation reactions?

_____

_____

_____

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Exercise 11 APPLICATIONS OF ORGANIC CHEMISTRY

1. Alkanes are the main component of fossil fuels.

   1.1 Name three fossil fuels.

   _____

   1.2 Explain briefly why alkanes are a non-renewable energy source, while alcohols are renewable.

   _____

   _____

   _____

   1.3 What is the main use of alkanes? _____

   1.4 What products are formed when an alkane burns in excess oxygen?

   _____

   1.5 Complete the following table by writing the equation for combustion in excess oxygen for each of the first eight alkanes.

Alkane	Equation for combustion in excess oxygen
Methane	
Ethane	
Propane	
Butane	
Pentane	
Hexane	
Heptaan	
Octane	

2. In what way and under what reaction conditions do esterification reactions (ie the preparation of an ester) take place?

   _____

   _____

   _____

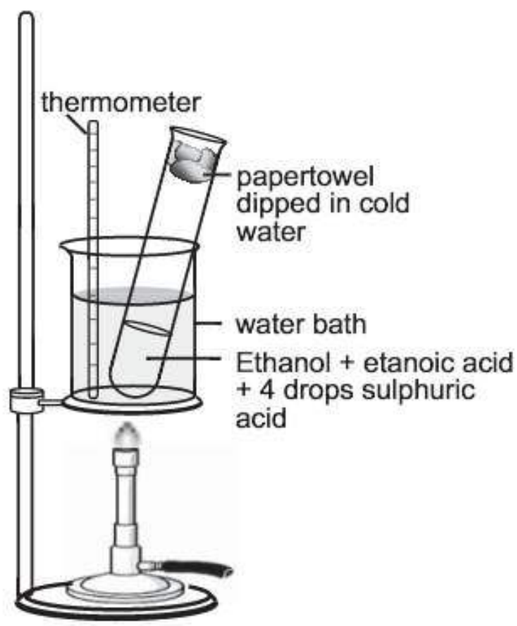
3. Use the alcohol and acid combinations to complete the following table:

Alcohol	Carboxylic acid	Name of Ester	Structural formula
Ethanol	Butanoic acid		

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Alcohol	Carboxylic acid	Name of Ester	Structural formula
Ethanol	Hexanoic acid		
Methanol		Methyl propanoate	
	Butanoic acid	Penthyl butanoate	

4. Many of the flavors and smells of fruit are esters. The general ester which is found in wine and contributes to the perception of fruitiness in wine is ethyl methanoate.
A learner wants to prepare ethyl methanoate in the school laboratory. She sets up the apparatus as shown in the diagram.



4.1 To which homologous series does ethanol belong? _____

4.2 What is the function of the sulphuric acid during the reaction?

_____

4.3 Why does this method use a water bath instead of direct heat over an open flame?

_____

_____

_____

_____

4.4 State ONE function of the wet paper towel in the opening of the test tube.

_____

4.5 Use structural formulas to write a balanced equation for the reaction that takes place in the test tube.

4.6 The learner finds it difficult to observe the smell of the ester, due to the presence of sulfuric acid and unreacted ethanoic acid. A friend suggests that she should add 10 drops of a diluted sodium bicarbonate to the contents of the test tube. Explain briefly why this suggestion can be a potential solution to the problem.

_____

4.7 Although several esters can be present in wine, the perceived aroma in wine is usualy that of the smalest ester present, namely ethyl ethanoate. Name a physical characteristic of ethyl ethanoate which is responsible for this.

_____

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5. 5.1 Use (1) structural formulae and (2) condensed structural formulae to write down the following reactions. Label all reactants and products in full.

5.1.1 Reaction between ethanol and propanoic acid.

(1)

(2)

5.1.2 Preparation of penthyl propanoate.

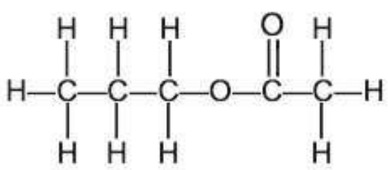
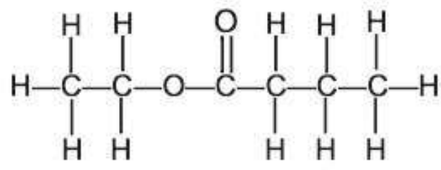
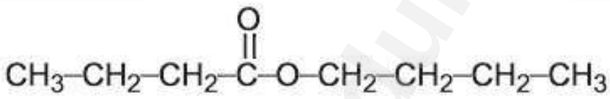
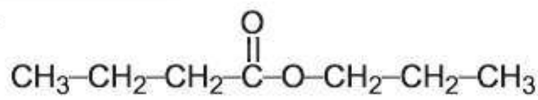
(1)

(2)

5.2 State the common name given to the reaction mentioned above. _____

5.3 Give the name and formula of the catalyst that is used. _____

6. Give the IUPAC-name for each of the following esters:

6.1 	6.2 
6.3 	6.4 

7. Draw the structural formula of the following esters:

7.1 methyl methanoate

7.2 ethyl hexanoate

7.3 prophyl butanoate

7.4 hexyl etanoate

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TYPE OF REACTIONS OF ORGANIC CHEMISTRY

ADDITION, ELIMINATION AND SUBSTITUTION REACTIONS

Organic compounds undergo different reactions, depending on factors such as:

- Whether the compounds are saturated or unsaturated.
- With what the compound reacts.
- The reaction condition i.e. the condition under which the reaction occurs such as when a catalyst is used or that the reaction occurs at high temperatures.

We will study the following different types of reactions:

- **Addition reactions**
  - atoms are added to break the double or triple carbon-carbon bond.
  - no atoms are removed from the molecule.
  - a more saturated product is formed.
  - the number of molecules decrease as a result of the reaction.
- **Elimination reactions**
  - the number of double or triple carbon-carbon bonds increase.
  - the number of molecules increase as a result of the reaction.
- **Substitution reactions**
  - An atom or group of atoms bound to the carbon atom are displaced by another atom or group of atoms.
  - The number of molecules remain unchanged as a result of the reaction.

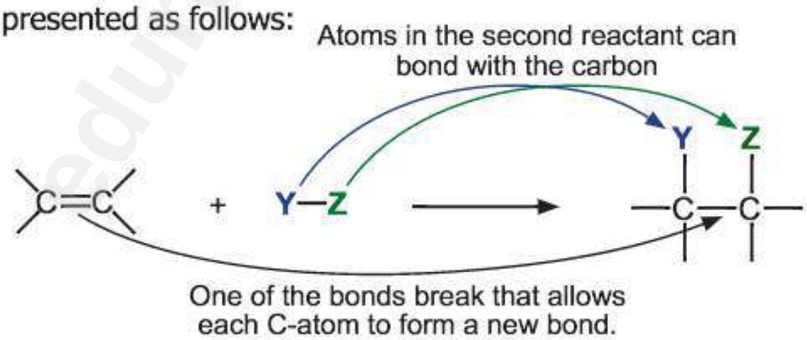
ADDITION REACTIONS

An addition reaction is a chemical reaction in which atoms or groups of atoms are added to a molecule by breaking the double or triple bond between the C-atoms without removing any atoms from the molecules.

Unsaturated hydrocarbons such as alkenes and alkynes undergo addition reactions to form saturated compounds. During an addition reaction two or more molecules react with one another to create a single molecule. Thus two or more reactants react to form a single product. This product contains all the atoms present in the reactants. The general equation for an addition reaction is: **A + B → C.**

When an alkene undergoes an addition reaction, atoms or groups of atoms are added to the alkene molecule by breaking the double bond between the C-atoms without removing any atoms from the molecule. The double bond is now a single bond between two C-atoms. Two new single bonds form which makes it possible for the atoms or groups of atoms to bond to the molecule.

An addition reaction can be presented as follows:



The Alkenes undergo different types of addition reactions depending on the compound (reactant) which is added to the alkene. We will now study the different types of addition reactions that can occur.

1. Hydrogenation

Hydrogenation is the addition of hydrogen to an alkene.
With an **addition reaction hydrogen** (H_2) is added to the alkene.

Reaction conditions:
- An alkene should be dissolved in a non-polar solvent ($CC\ell_4$) with a catalyst such as platinum (Pt), palladium (Pd) or nickel (Ni). H_2-gas is bubbled into the container
- No water must be present during this reaction.

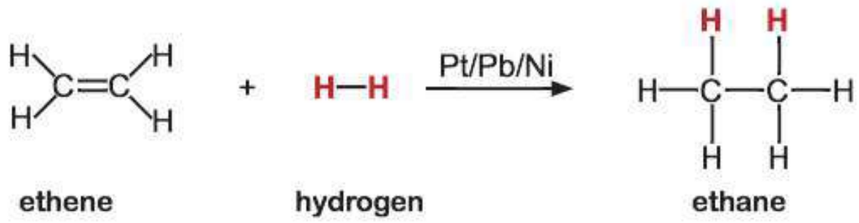
Reactants: alkenes + H_2
Products: alkanes

$$\text{Alkene} + H_2 \rightarrow \text{alkane}$$

During the hydrogenation reaction the double bond in the alkene is broken and hydrogen atoms bond to two C-atoms between which the double bond was. The catalyst, in its divided state, lowers the activation energy of the reaction providing a platform on which the reactants can get into closer contact with each other, in order for the product (alkane) to form. An unsaturated alkene is converted in this reaction into a saturated alkane.

The following equation shows the hydrogenation of ethene (C_2H_4) to ethane by the addition of hydrogen to ethene. The reaction is also shown by making use of structural formulas.

$$C_2H_4 + H_2 \xrightarrow{Pt/Pb/Ni} C_2H_6$$



ethene + hydrogen → ethane

- ***Hydrogenation of plant oils:***

Margarine is manufactured in the industry by the hydrogenation of unsaturated vegetable oils, such as sunflower oil and soja bean oil. Hydrogenation (i.e. the addition of hydrogen to an alkene) changes these unsaturated plant oils into saturated compounds that have higher melting points and are more likely solids than liquids. Solids of this type can be used to manufacture margarine and other fats by adding color and flavorings.



2. Halogenation

Halogenation is the addition of a halogen to an alkene.
I.e. at a **halogenation reaction** a **halogen molecule**, X_2 (**X** = **Cℓ**, **Br**, **I**) is added to an alkene.

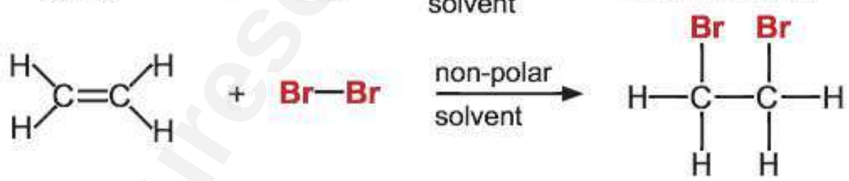
Reaction conditions: • X_2 dissolved in non-polar solvent ($CC\ell_2$).
• No water must be present during the reaction.
The reaction is spontaneous and occurs easily at room temperature. No catalyst is required and the reaction proceeds in a nonreactive solvent, without adding heat or sunlight.

Reactants: alkenes + X_2 (**X** = **Cℓ**, **Br**, **I**)
Products: haloalkanes

Alkene + X_2 → haloalkane

Alkenes readily react with chlorine, bromine and iodine to form saturated bonds, with two halogen atoms on either side of the carbon where the double bond has been broken.
The following equation shows the halogenation of ethene (C_2H_4) to 1,2-dibromoethane with the addition of bromine to ethene. The reaction is also shown by the use of structural formulas.

$$C_2H_4 + Br_2 \xrightarrow[\text{solvent}]{\text{non-polar}} CH_2BrCH_2Br$$



ethene + bromine → 1,2-dibromoethane

- The reaction where **bromine** (Br_2) is added, is a test to distinguish between saturated and unsaturated hydrocarbons.

Test for unsaturated hydrocarbons

- *Add a few drops of bromine water that is orange-brown in color to the unknown hydrocarbon and shake.*
- *If the mixture discolours immediately without the application of heat or light, then It was an unsaturated hydrocarbon (alkene or alkyne).*
- *If the orange-brown color only disappears when energy (eg. heat or light) is added it was a saturated hydrocarbon, namely an alkane.*

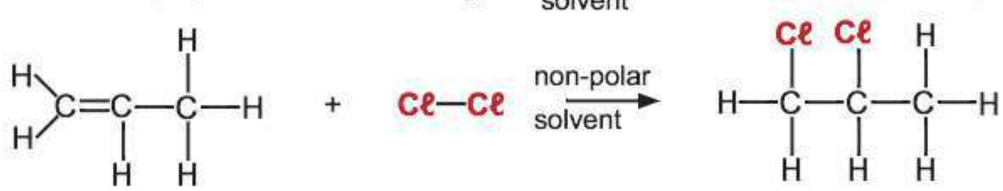
(Refer to Experiment 1, Part 1 and the substitution reactions namely halogenation at alkanes in this chapter.)



bromine water discolors alkenes through halogenation reactions

Another example of a halogenation reactions is the reaction between propene (C_3H_6) and chlorine ($C\ell_2$) to form 1,2-dichloropropane. The reaction is also shown by the use of structural formulas.

$$C_3H_6 + C\ell_2 \xrightarrow[\text{solvent}]{\text{non-polar}} CH_2C\ell CH_2C\ell CH_3$$



propane + chlorine → 1,2-dichloropropane

3. Hydrohalogenation

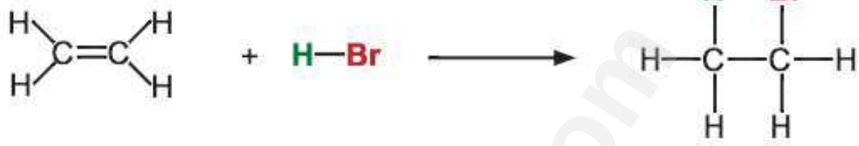
Hydrohalogenation is the addition of a hydrogen halide to an alkene.
With an **hydrohalogenation reaction hydrogen halide HX** (**X = Cℓ, Br, I**) is added to the alkene.
Reaction conditions: • Anhydrous HX is used. The dry HX is directly added to the alkene.
(This is to prevent bonding with an OH group.)
Reactants: alkenes + HX (X = Cℓ, Br or I)
Products: haloalkanes

Alkene + HX → haloalkane

The hydrogen atom bonds to the one a carbon of the broken double bond and the halogen atom bonds to the other carbon of the broken double bond.

The following equation shows the hydrohalogenation of ethene (C_2H_4) to bromoethane by the addition of HBr to ethene. The reaction is also shown by the use of structural formulas.
Note that **ethene is a symmetrical alkene** because both C-atoms on either side of the double bond are bonded to the same number and types of atoms. The two C-atoms are identical and the bromine can bind to anyone of the two C-atoms.

C_2H_4 + HBr → CH_3CH_2Br

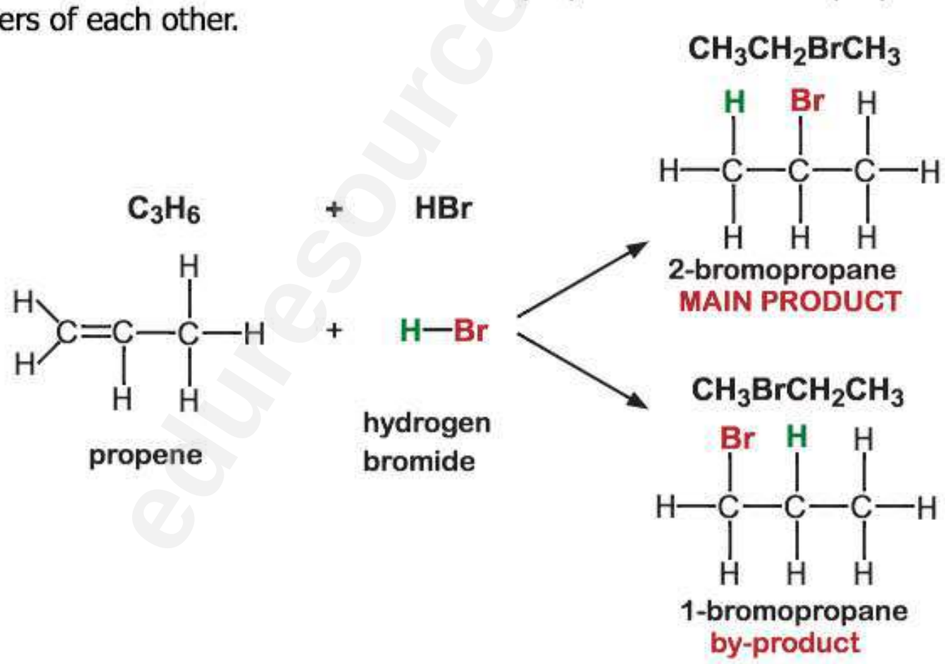


ethene + hydrogen bromide → bromoethane

• Addition of HX to asymmetric alkenes

During the addition reaction of a hydrogen halide to a **asymmetric alkene** (through hydrohalogenation), two different products can be produced.

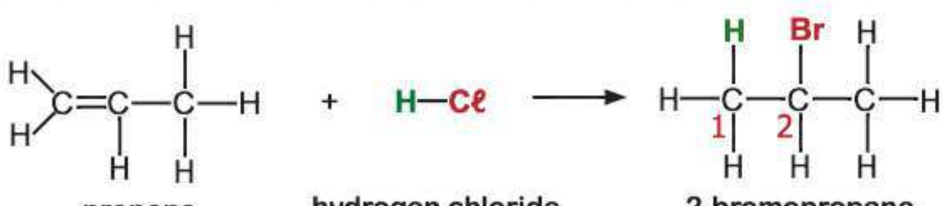
For example if propene reacts with HBr it forms 1-bromopropane and 2-bromopropane. Two products are thus possible and are isomers of each other.



Between the two reactions of HBr and propene, in practice 2-bromopropane would rather be produced as the main product.
In order to determine the main product we make use of the rule of the Russian scientist, Vladimir Markovnikov (1838- 1904), to indicate which carbon will get the H-atom and which carbon will get the Br atom.

Markovnikov's rule: During the addition of HX (X = Cℓ, Br, I) to an asymmetrical alkene:
• the H-atom bonds to the C-atom with the most (larger number) of H atoms.
• the X-group bonds to the C-atom with the least H atoms.

Consider the addition of HBr to propene in the example above. According to Markovnikov's rule, the H-atom bonds to the C_1-carbon, with the most H-atoms. The Br atom bonds to the C_2-carbon, with the least H-atoms.



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4. Hydration

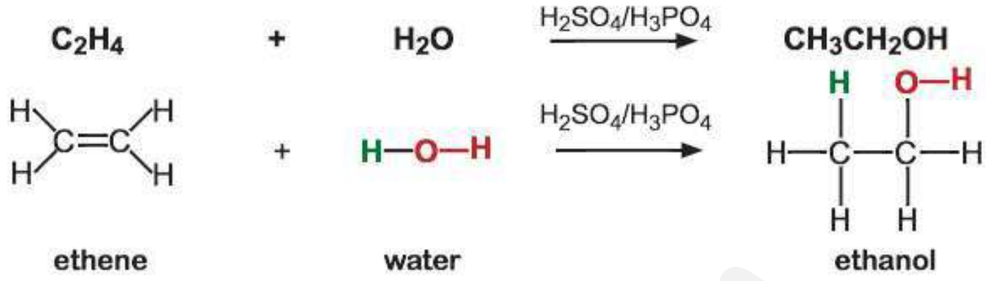
Hydration is the addition of a water to an alkene.
With a **hydration reaction** a **water** (H_2O) is added to the alkene.

Reaction conditions:
- H_2O is added in excess.
- Small amount of a strong acid such as sulfuric acid (H_2SO_4) or phosphoric acid (H_3PO_4) is used as catalyst.

Reactants: alkene + H_2O
Products: alcohol

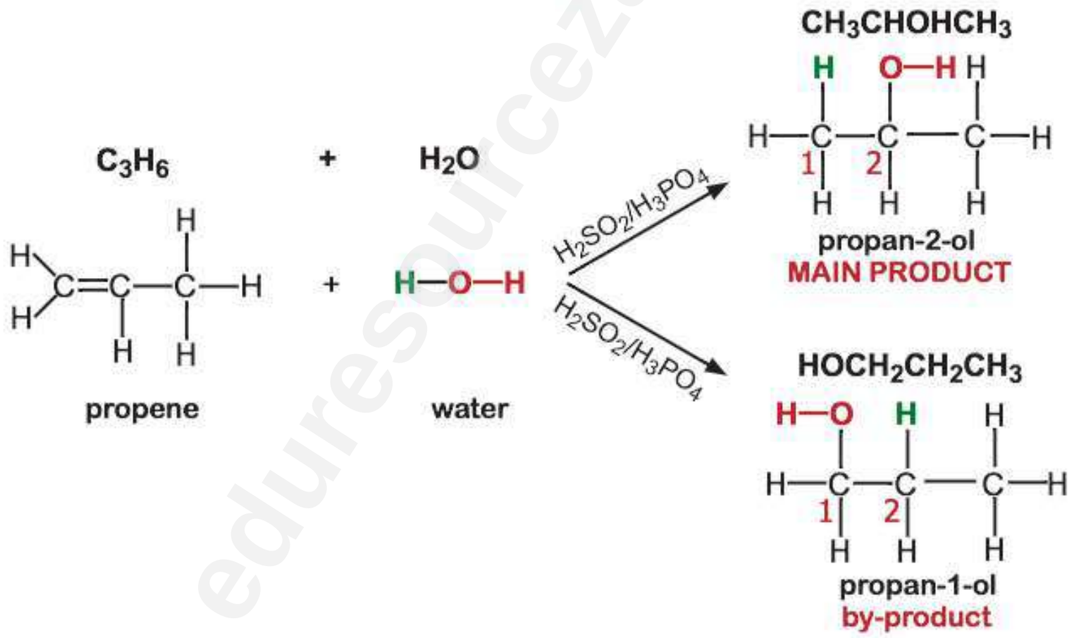
Alkene + H_2O → alcohol

The following equation shows the hydration from ethene (C_2H_4) to ethanol by the addition of H_2O to ethene. The reaction is also shown by the use of structural formulas.



The addition of water **to an asymmetric alkene** also takes place according to **Markovnikov's rule.**
- the H-atom bonds to the C-atom with the most (larger number) H-atoms.
- the OH-group bonds to the C-atom with the least H atoms.

Consider the hydration from propene (C_3H_6) to propan-2-ol by the addition of H_2O to propene. According to Markovnikov's rule the H-atom bonds to the C_1-carbon, with the most H-atoms. The OH-group bonds to the C_2-carbon, with the least H-atoms. Propan-2-ol is the **main product**. Propan-1-ol the by-product.



Addition reaction in the industry

Many useful substances are manufactured in the industry with the help of addition reactions. In industrial processes addition reactions occur between unsaturated compounds that produce products such as:
- Polyethylene, which is used to manufacture many plastic bottles, plastic cling wrap and cable isolation.
- Polypropylene, are used in packaging and labeling, such as textiles like ropes and mats, stationery and plastic auto parts.
- Polyvinyl chloride (PVC), is used in construction and plastic pipes.


Polyethylene has many uses.

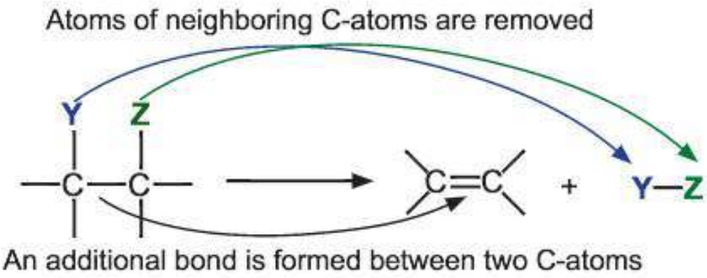
ELIMINATION REACTIONS

An elimination reaction is a chemical reaction in which atoms or groups of atoms are removed from two adjacent C-atoms in a saturated organic molecule.

Saturated compounds such as alkanes, haloalkanes and alcohols undergo elimination reactions. During an elimination reaction a reactant is broken down into two products. Thus one reactant breaks up to form two products.
The general equation for an elimination reaction is: **A → B + C.**

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An **elimination reaction is the opposite of an addition reaction**. Instead of atoms or groups of atoms added to the double bond in order to form a saturated molecule, atoms or groups of atoms are removed from two adjacent C-atoms of a saturated molecule to form a double bond. In other words, saturated organic compounds undergo elimination reactions to form unsaturated compounds. This process is used during the cracking of petroleum, where less active bigger alkanes are broken down into smaller more active alkenes.
An elimination can be represented as follows:



We study the different types of elimination reactions that occur at the saturated organic compounds of alkanes, haloalkanes and alcohols.

1. Dehydrohalogenation

Dehydrohalogenation is the elimination of HX (X = Cℓ, Br, I) from a haloalkane.
In a dehydrohalogenation reaction an **HX** is removed from the haloalkane. This occurs when a **hydrogen atom** is eliminated (removed) from a carbon atom and a **halogen atom, X** (**Cℓ, Br, I**) is eliminated (removed) from an adjacent carbon atom of a haloalkane molecule.

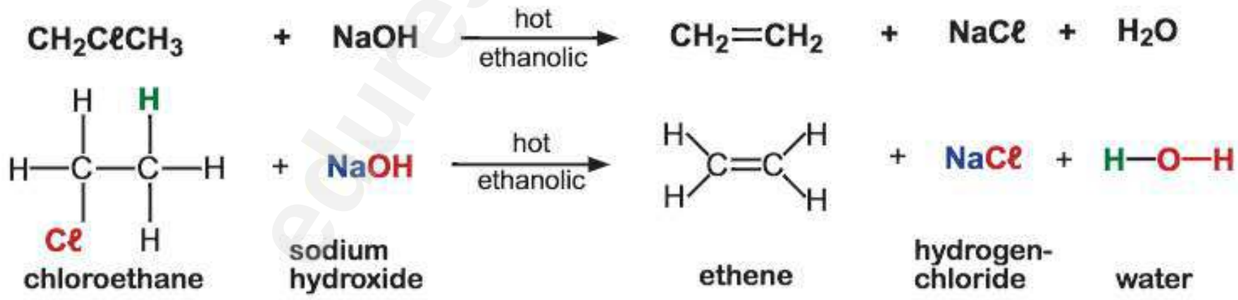
Reaction conditions:
- Dissolve base in ethanol.
- A concentrated solution of a strong base such as sodium hydroxide (**NaOH**), potassium hydroxide (**KOH**) or Lithium hydroxide (**LiOH**) is dissolved in pure ethanol.
  (Hot ethanolic **NaOH, KOH** or **LiOH**).
- Strongly heated with **reflux** - the vapor condenses and returns to the reaction flask during heating).

Reactants: haloalkanes + concentrated strong base

Haloalkane + concentrated strong base $\xrightarrow{\text{warm ethanolic}}$ alkene + salt + H_2O

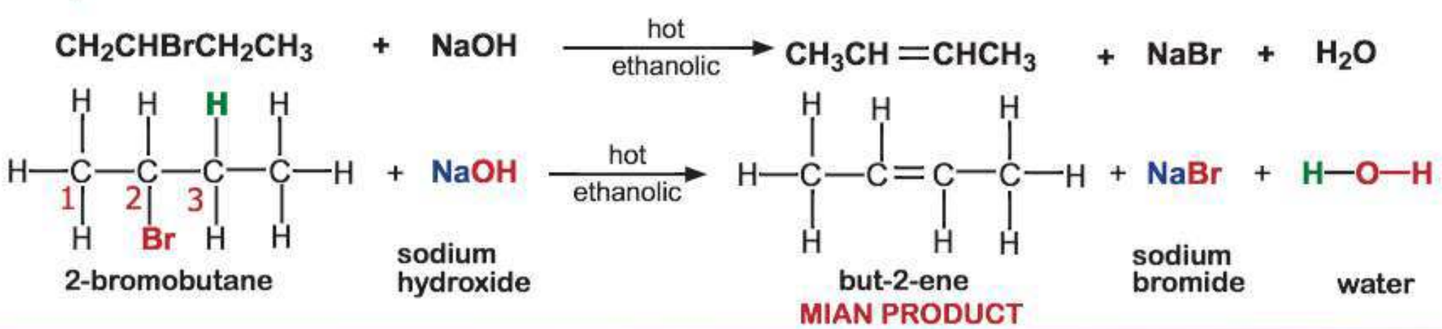
Products: alkenes + salt + H_2O

The following equation shows the dehydrohalogenation of chloroethane to ethene by elimination of **HCℓ** from chloroethane. The reaction is also shown by the use of structural formulas.

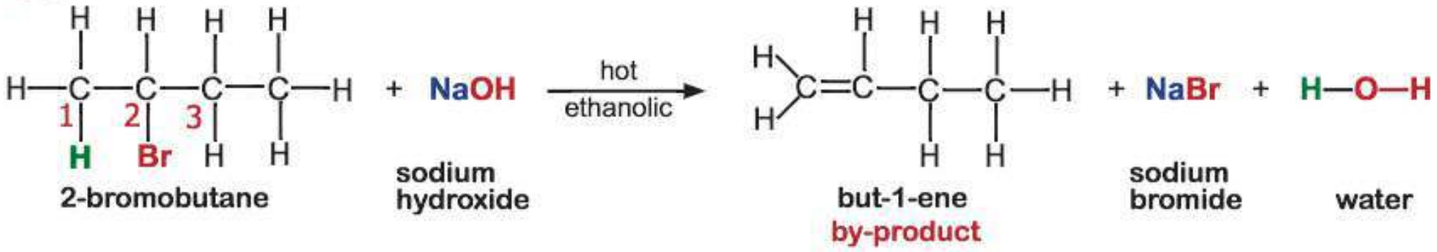


- Some haloalkanes can have two different alkenes as products of elimination. During the elimination of hydrogen and a halogen from haloalkanes of which the C-chain **consists of more than three C-atoms** more than one alkene can form as product.
- ***The main product is the one in which the hydrogen atom is removed from the least substituted carbon atom, i.e. from the C-atom which has the least H-atoms.***

The bromine atom of 2-bromobutane is removed from C_2. The hydrogen atom must now be removed from a carbon atom closest to C_2. The hydrogen atom can be removed from C_1 or C_3. The C_1 atom has three hydrogen atoms bonded to it, while C_2 has two hydrogen atoms bonded to it. C_3 has fewer hydrogen atoms and will lose the hydrogen atom to form the main product.
The **main product** is **but-2-ene**.



The **by-product** is **but-1-ene**.



2. Dehydration

Dehydration is the elimination of water from an alcohol.

In a dehydration reaction the **water** from an alcohol is removed to form an alkene. This is done by eliminating (removing) an **H-atom** of one carbon atom and an **OH-group** of an adjacent carbon atom from an alcohol molecule.

Reaction conditions: • Alcohol strongly heated with sulphuric acid (H_2SO_4) or phosphoric acid (H_3PO_4) as a catalyst. (Is an acid catalyst dehydration reaction. The acid is a dehydrating catalyst (removes water). Mixture should be strongly heated in the presence of the catalyst.)

Reactants: alcohol + concentrated H_2SO_4 (or H_3PO_4)

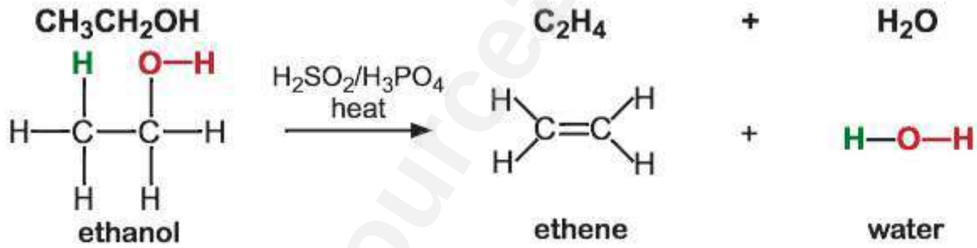
Products: alkenes + H_2O

$$\text{Alcohol} \xrightarrow[\text{or } H_3PO_4]{\text{concentrated. } H_2SO_4} \text{alkene} + H_2O$$

When an alcohol is heated with concentrated sulfuric acid (H_2SO_4) or phosphoric acid (H_3PO_4) as catalyst, the alcohol loses an **OH**-group and a **H**-atom on neighboring **C**-atoms to form an alkene. The reaction can be carried out only on alcohols containing at least one **H**-atom on a neighboring **C**-atom. Methanol, CH_3OH can not.

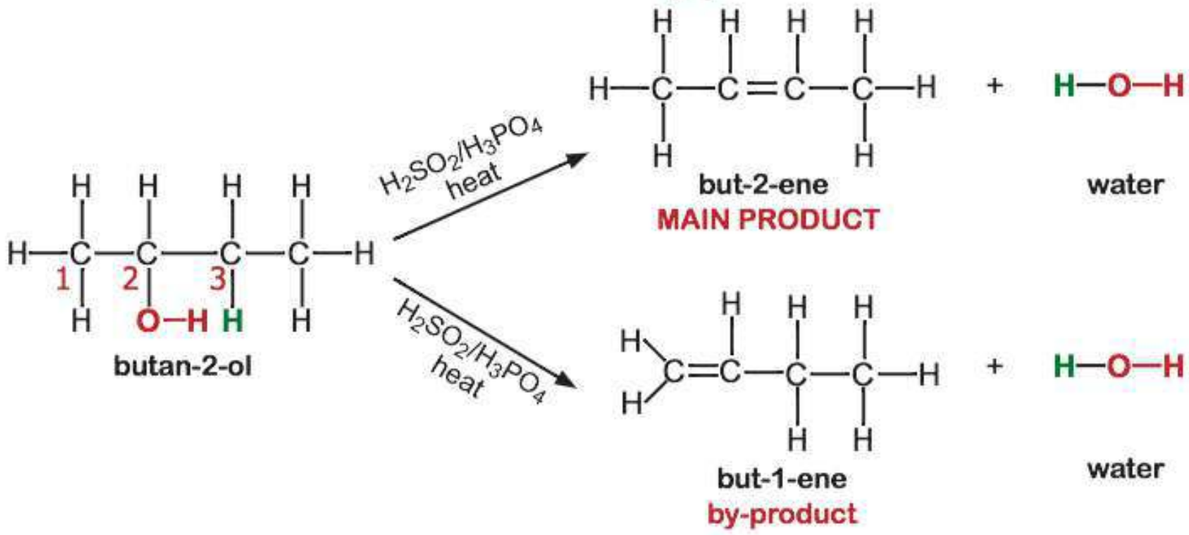
Elimination of water from the alcohol is the opposite of the addition of water to an alkene.

The following equation shows the elimination of water from ethanol. The reaction is also shown by the use of structural formulas.



- Certain alcohols, can produce two different alkenes as products of elimination. During the elimination of water from alcohol where the C-chain contains more than **three C-atoms,** more than one alkene as product can be formed.
- ***The main product is the one in which the hydrogen atom is removed from the least substituted carbon atom, i.e. from the C-atom which has the least H atoms.***

For the elimination reaction performed on butan-2-ol, as shown below, an H-atom bonded to a C-atom and an OH-group bonded to an adjacent C-atom must be removed. Because in this case more than one elimination product is possible, the main product is the one where the H-atom is removed from the adjacent C-atom with the smallest number of H-atoms. This is the H-atom of the C_3-atom adjacent to the C_2-atom which contain the OH-group. The **main product** is then **but-2-ene** with **but-1-ene** as a **by-product**.



3 Cracking of hydrocarbons

After crude oil is separated into its various fractions by fractional distillation, it is not the end of the story. All these fractions require further treatment before they can be used. Fractions like naphtha (C_6 - C_{10}), karosene (C_{10} - C_{15}) and diesel (C_{15} - C_{20}) are very large hydrocarbon molecules consisting of long carbon chains.

Chemists have found that these larger molecules in the heavier fractions can be broken up into smaller, lighter molecules. For example a molecule with 18 C-atoms per molecule may break up into two molecules, each with 9 C-atoms, or two molecules, one with 10 C-atoms and the other with 8 C-atoms. Thus, the heavier fractions of crude oil can change into petrol! These are the shorter chain hydrocarbons that are the best sustances to use as fuel because they burn more readily than the longer chain molecules.

Cracking is the name used when longer less active hydrocarbon molecules are broken down into smaller, more active and more useful molecules. This is achieved by using high pressure and temperature without a catalyst, or a lower temperature and pressure in the presence of a catalyst.

Cracking is the process by which longer chain hydrocarbon molecules are broken down into shorter and more useful molecules.

Cracking of alkanes is a example of an **elimination reaction** and is used in the industry of fuel to obtain a greater percentage of useful products from crude oil fractions. During the process of cracking one of the products **always** is **an alkene**. Few alkenes are found freely in nature. Cracking provides chemists with a good source of alkenes.

The fractions can be cracked (broken up) by the use of two methods, namely, **thermal cracking** and **catalytic cracking**.

- **Thermal cracking**

  Thermal cracking is the cracking of hydrocarbons under the conditions of **high pressure and high temperature** without a catalyst to crack (to break) the larger fractions of crude oil into shorter and more useful molecules.

  Reaction conditions: • High temperature (800 °C) and high pressure (700 atm)
  Reactants: Alkanes

- **Catalytic cracking**

  Catalytic cracking is the cracking of hydrocarbons under the conditions of **low pressure and low temperature** with a **catalyst** to crack (to break) the larger fractions of crude oil in shorter and more useful molecules.

  Reaction conditions: • Low temperature (800 °C), low pressure (1 atm) in the presence of a catalyst (Pt, Pd, or Ni).
  Reactants: Alkanes
  Products: Alkenes + alkanes / alkenes + H_2



A Catalytic cracker at a oil refinery.

- **Predict the range of products which form with cracking**

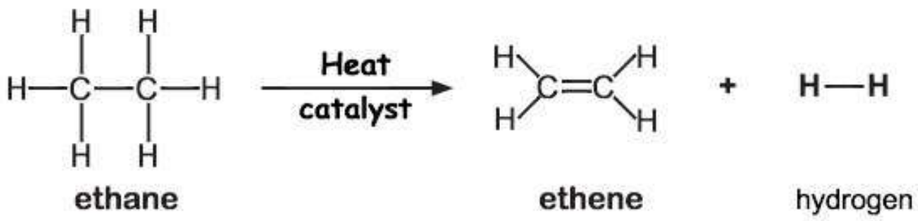
All cracking reactions form one or two series of products:

- An alkane with a shorter chain length than the original alkane and alkene with a short chain length.
  - It has a better chance of occurring because 346 $kJ \cdot mol^{-1}$ energy is required to break the C-C bonds which is less than required for the C-H bonds to break.
- One or more alkenes and hydrogen.
  - It has less chance of occurring because 435 $kJ \cdot mol^{-1}$ energy is required to break the C-H bonds which are more than 346 $kJ \cdot mol^{-1}$.



Examples of catalysts for catalytic cracking.

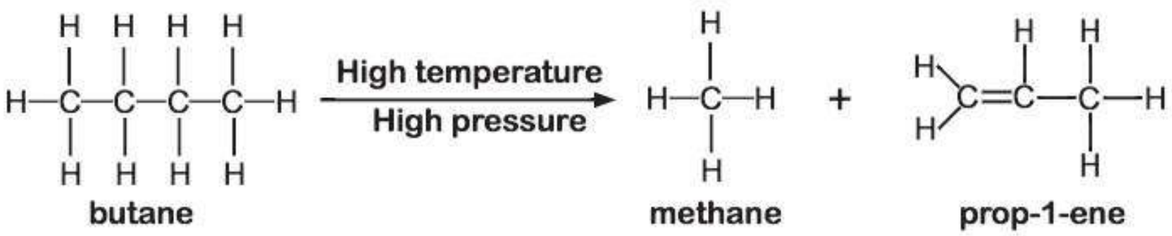
Ethene is produced by cracking of ethane, as illustrated in the following reaction:



ethane **ethene** hydrogen

The cracking of butane:

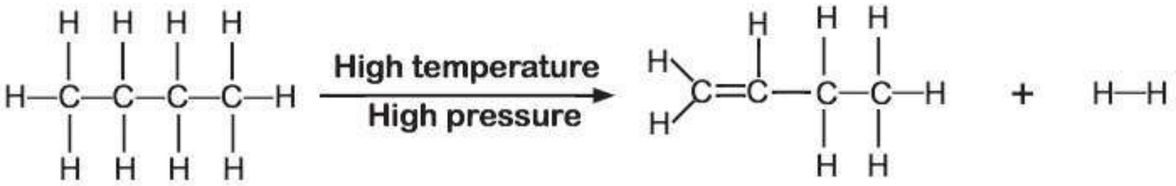
- Products formed by the breaking of C-C bonds. A shorter length of alkane than butane and an alkene is formed.



butane **methane** **prop-1-ene**

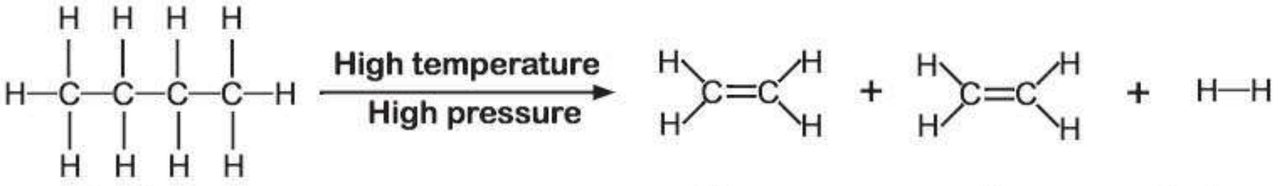
• Products formed by the breaking of C-H bonds.

- An alkene and hydrogen can form:



butane — but-1-ene — hydrogen

- Or two alkenes and hydrogen can form:



buthane — ethene — ethene — hydrogen

Importance of cracking

Petrol

- The amount of gasoline obtained from crude oil is insufficient to meet the demand for gasoline.
- Heavy fractions are less in demand and can be cracked to produce extra gasoline.

Alkenes

- Hydrocarbons in crude oil are unreactive. They are converted into alkenes which are very reactive.
- Alkenes are used for making alcohol and plastics.

Hydrogen

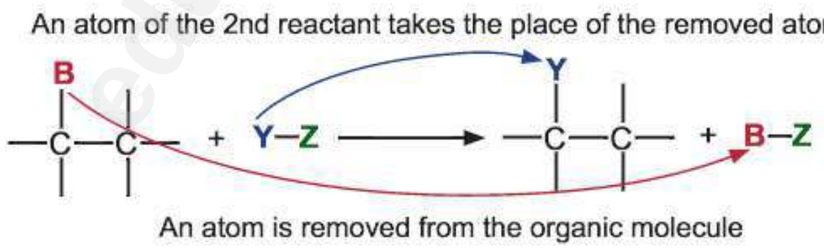
- Hydrogen is used to make ammonia in the Haber process, and used as rocket fuel in hydrogen fuel cells.

SUBSTITUTION REACTIONS

A substitution reaction is a chemical reaction in which an atom or group of atoms in a molecule are displaced by another atom or group of atoms.

Saturated hydrocarbons such as alkanes, haloalkanes and alcohols undergo substitution reactions. During a substitution reaction two reactants react with each other to form two products, i.e. the number of molecules remain the same. During the reaction a swapping of atoms or groups of atoms take place in the reactants. The general equation for an sustitution reaction is: **AB + CD → AD + BC.**

An elimination reaction can be represented as follows:



1 Substitution reactions at the alkanes: halogenation - conversion of alkanes to haloalkanes

Alkanes react readily with the halogens **F_2**, **$C\ell_2$**, **Br_2** and **I_2** when heated (indicated by **Δ**) or under the influence of light eg. sunlight or ultraviolet light (indicated with energy equal to **hf**, where **h** is Planck's constant and **f** is the frequency of the light absorbed). A **substitution reaction** occurs where the hydrogen atom in the alkane is displaced, one at a time, by a halogen atom to form a **haloalkane and a hydrogen halide as products**.

Reaction conditions: • Heat or sunlight (UV light). This reaction is extremely slow.

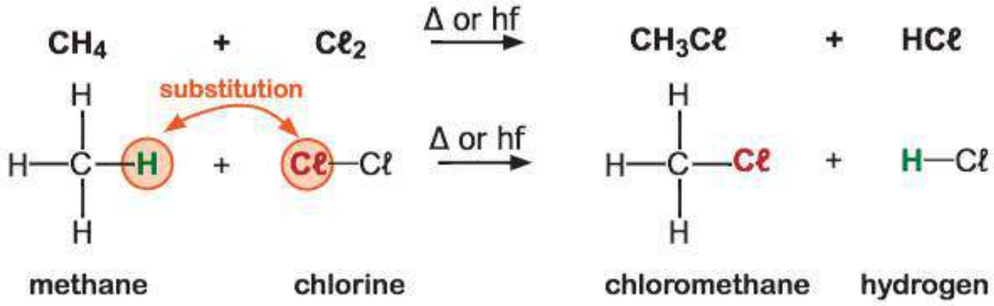
Reactants: alkanes + X_2 (X = F, Cℓ, Br or I)

Products: haloalkanes + HX

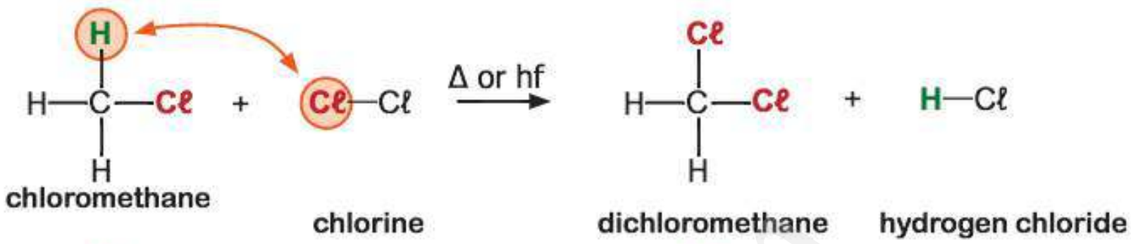
$$\text{Alkane} + X_2 \xrightarrow{\Delta \text{ or } hf} \text{haloalkane} + HX$$

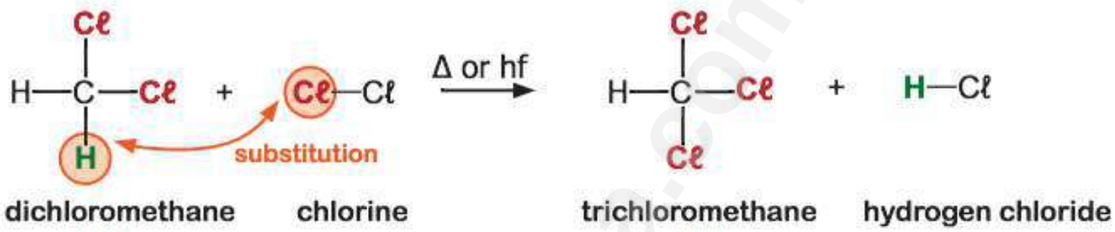
To test whether a hydrocarbon is saturated or not, add **Br_2** to the hydrocarbon. If the solution decolourise slowly with UV light, a **substitution reaction** occurred and the hydrocarbon is saturated (an alkane). If the discoloration occur quickly, an **addition reaction** occurred and the hydrocarbon is unsaturated (alkene or alkyne).

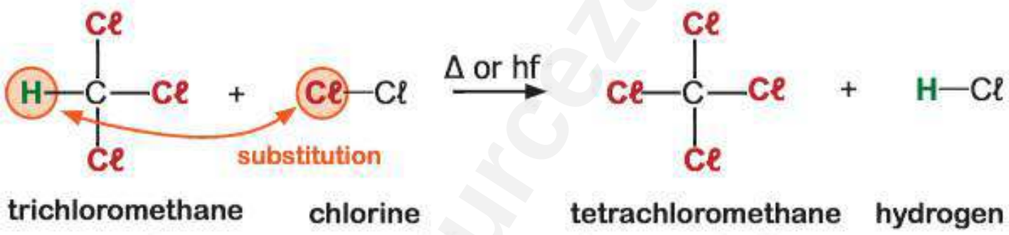
Consider the equation for the reaction of methane and chlorine that occurs in the presence of heat or light.
The reaction is also shown by the use of structural formulas.



When methane is in excess, chloromethane is the main product. If there is an excess of chlorine, the other hydrogen atoms also get substituted. With chlorine in excess the substitution reaction is difficult to stop and additional substitution reaction will take place by substituting one atom at a time, until all the H-atoms are substituted.



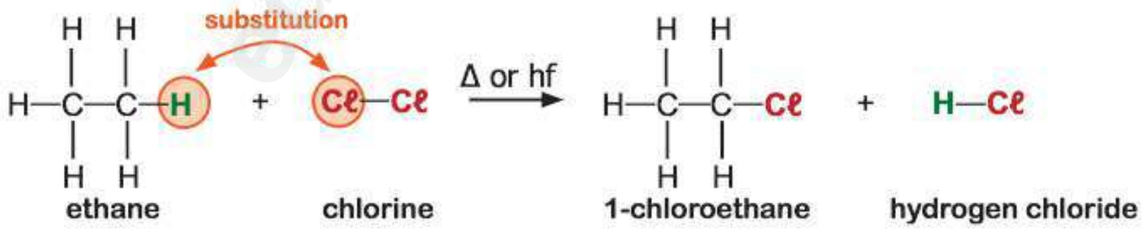




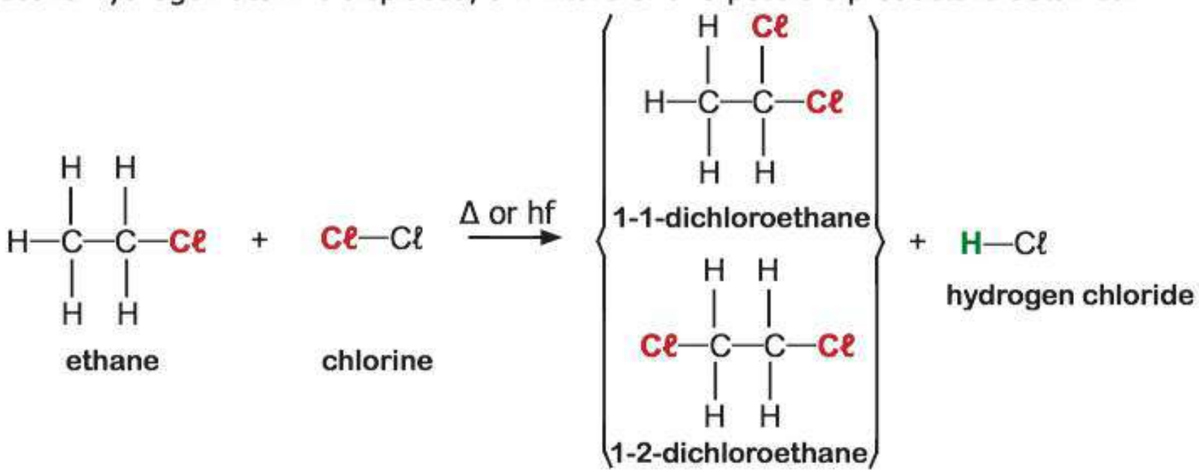
At the end of the reaction there is a mixture of these products. With chlorine in excess tetrachloromethane will be the main product.

A similar, but faster, reaction will occur when fluorine is used instead chlorine. The reactivity of the halogen is in the following order $F_2 > Cℓ_2 > Br_2 > I_2$. Fluorine reacts explosively with alkanes while iodine is much less active (inert) with alkanes.

When an alkane with more than one C-atom reacts with a halogen, eg. $Cℓ_2$, the reaction is more complex.
The first step in the chlorination of ethane gives a product which contains one Cℓ-atom per molecule.



- When a second hydrogen atom is displaced, a mixture of two possible products is obtained.



The product mixture does not contain an equal number of moles of dichloroethane, so we do not show a balanced stoichiometric equation. Because the reaction of saturated hydrocarbons with a halogen may produce many products the reaction is not always as useful as is required.

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2. Substitution reactions at the alcohols: conversion of alcohols to haloalkanes by halogenation

Alcohols react with anhydrous hydrogen halides (**HX**, where **X** = **Cℓ**, **Br** or **I**) to form haloalkanes. During the reaction the carbon-oxygen bond breaks and the OH-group form the alcohol is replaced with a halogen atom. This reaction is the reverse of the hydrolysis of haloalkanes to form alcohols.

Reaction conditions:
- For tertiary alcohols - HBr or HCℓ added directly at room temperature.
- For rimary and secondary alcohols - Solid NaBr (or KBr) + H_2SO_4 is used to make HBr in a reaction flask. HBr reacts sloly with alcohol. Must be heated.

Reactants: alcohol + HX (X = F, Cℓ, Br of I)

Products: haloalkanes + H_2O

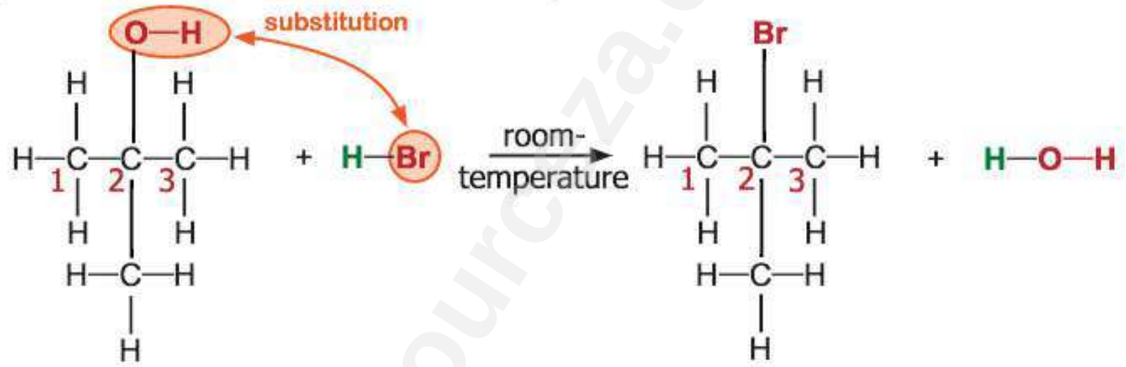
Alcohol + HX → haloalkane + H_2O

NOTE! For **primary and secondary alcohols** solid NaBr (or KBr) is added to concentrated H_2SO_4 in a reaction flask to form HBr. The reaction that occur is $NaBr + H_2SO_4 \rightarrow HBr + NaHSO_4$. When HBr reacts with a primary and secondary alcohol the reaction is slow, thus the reaction mixture must be heated for the reaction to take place. The reaction occurs more readily (easily) when HBr reacts with a tertiary alcohol. For **tertiary alcohols** HBr or HCℓ is directly added at room temperature.

2.1 Conversion of a tertiary alcohol to a haloalkane - at room temperature

Consider the reaction between the **tertiary alcohol** 2-methylpropan-2-ol and hydrogen bromide (HBr).
The reaction is shown by the use of structural formulae.

- 2-methyl-propan-2-ol is a **tertiary alcohol** because
  - carbon 2 (C_2) is a tertiary carbon, it is bonded to three other C-atoms.
  - the **-OH** group of the alcohol is bonded to the tertiary carbon.

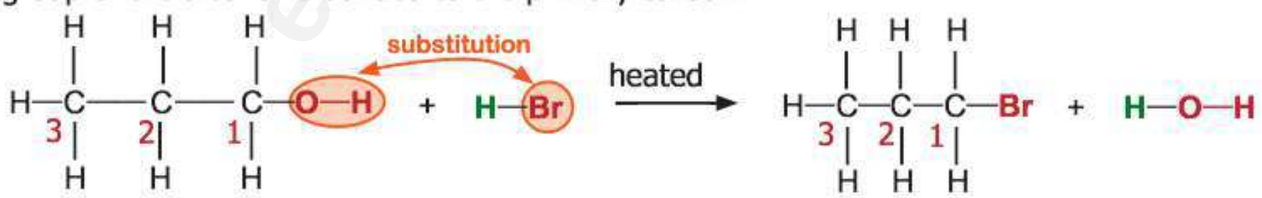


2-methylpropan-2-ol (tertiary alcohol) + hydrogen bromide → 2-bromo-2-methylpropane (tertiary haloalkane) + water

2.2 Conversion of a primary alcohol to a haloalkane - must be heated

Consider the reaction between the **primary alcohol** propan-1-ol and hydrogen bromide (HBr).

- Propan-1-ol is a **primary alcohol** because
  - carbon 1 (C_1) is a primary carbon, it is bonded to only one other carbon atom.
  - the **-OH** group of the alcohol is bonded to the primary carbon.

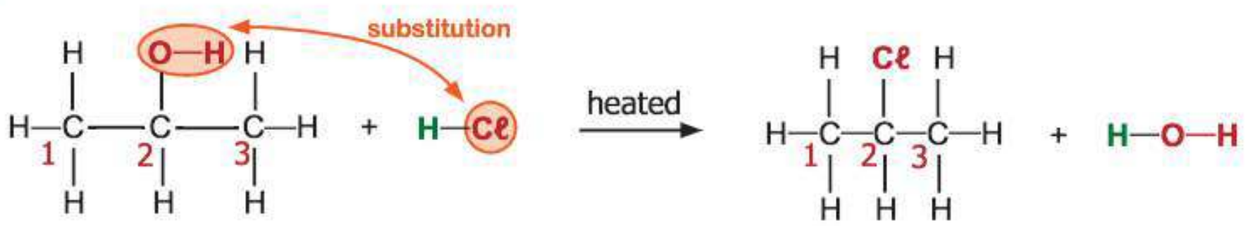


propan-1-ol (primary alcohol) + hydrogen bromide → 1-chloropropaan (primary haloalkane) + water

2.3 Conversion of a secondary alcohol to a haloalkane - must be heated

Consider the reaction between the **secondary alcohol** propan-2-ol and hydrogen bromide (HBr).

- Propan-2-ol is a **secondary alcohol** because
  - carbon 2 (C_2) is a secondary carbon, it is bonded to two other C-atoms.
  - the **-OH** group of the alcohol is bonded to the secondary carbon.



propan-2-ol (secondary alcohol) + hydrogen chloride → 2-chloropropane (secondary haloalkane) + water

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3. Substitution reactions at the haloalkanes: hydrolysis - conversion of alcohols to haloalkanes

Method 1

Haloalkanes can be converted to alcohols in substitution reactions by the use of aqueous solutions of strong bases such as **NaOH**, **KOH** and **LiOH**. (Remember a aqueous solution of a base is called an alkali.)
NaOH, **KOH** and **LiOH** contains an **OH**-group which subsitutes (replaces) the halogen atom in a haloalkane and converts the haloalkane to alcohol.

Reaction conditions:
- Diluted strong base (NaOH, KOH or LiOH).
- Dissolve the haloalkane in ethanol and heat the mixture moderately.
  (**Note:** This should be an aqueous solution of NaOH, KOH, or LiOH, i.e. a solution of a dilute strong base. A strong concentrated base will cause elimination instead of substitution.)

Reactants: alcohol + dilute strong base
Products: haloalkanes + salt (NaX or KX or LiX, where X = Cℓ, Br or I)

$$\text{Alcohol + diluted strong base} \xrightarrow[\text{and heat}]{\text{ethanol}} \text{haloalkane + HX}$$

Method 2

Haloalkanes can be converted to alcohols through substitution by making use of excess water.
H-OH (water) contains an **OH**-group which substitutes (replaces) the halogen atom in a haloalkane and converts the haloalkane to alcohol.

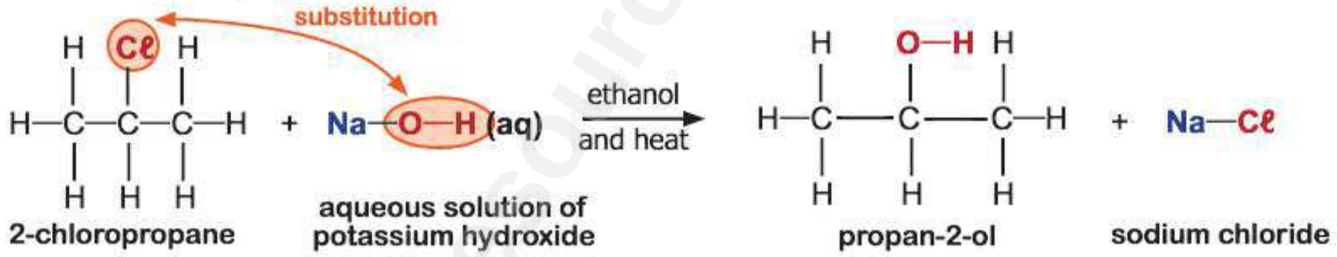
Reaction conditions:
- Add excess water.
- Dissolve the haloalkane in ethanol and heat moderately.

Reactants: haloalkane + H_2O
Products: alcohol + hydrogen halide (HX, where X = Cℓ, Br or I)

$$\text{Alcohol + } H_2O \xrightarrow[\text{and heat}]{\text{ethanol}} \text{haloalkane + salt}$$

Example 1: Method 1: Adding a water solution of NaOH (or KOH or LiOH)
- 2-chloropropane is dissolved in ethanol.
- An water solution of sodium hydroxide is added and the mixture is heated.

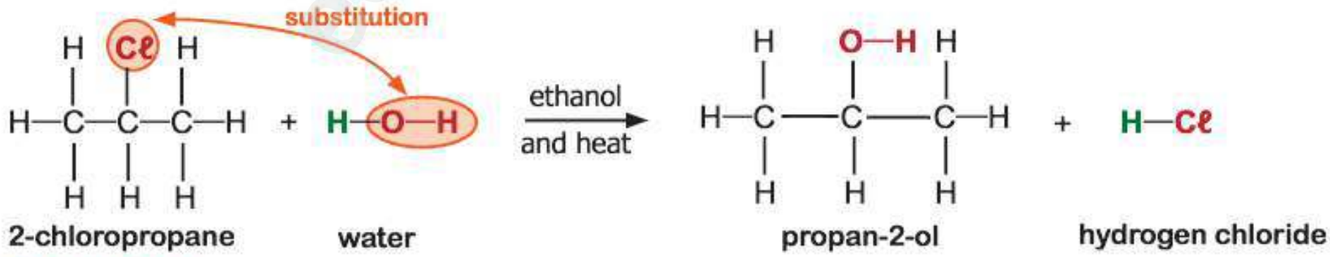
The reaction is as follows, by the use of structural formulas.



2-chloropropane | aqueous solution of potassium hydroxide | propan-2-ol | sodium chloride

Method 2: Adding only water without NaOH (or KOH or LiOH)
- 2-chloropropane is dissolved in ethanol.
- Water is added and the mixture is heated.

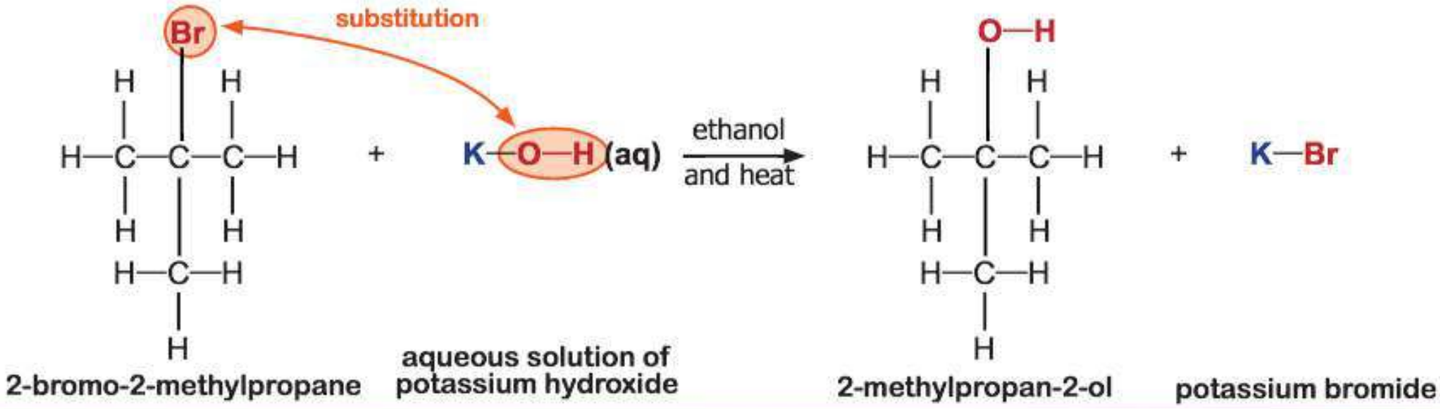
The reaction is as follows, by the use of structural formulas.



2-chloropropane | water | propan-2-ol | hydrogen chloride

Example 2: Method 1: Adding a aqueous solution of KOH (or NaOH or LiOH)
- 2-bromo-2-methyl propane is dissolved in ethanol.
- A aqueous solution of potassium hydroxide is added and the mixture is heated.

The reaction is as follows, by the use of structural formulas.

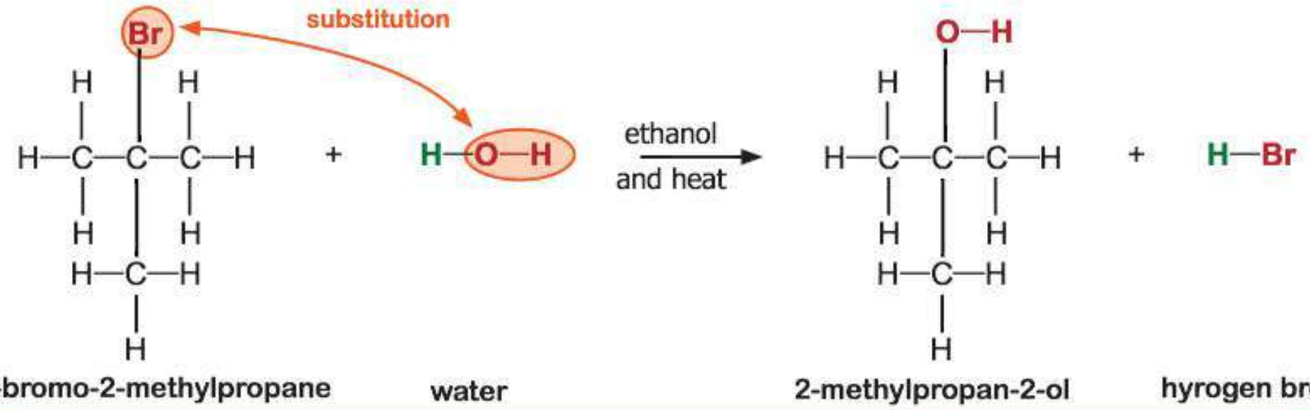


2-bromo-2-methylpropane | aqueous solution of potassium hydroxide | 2-methylpropan-2-ol | potassium bromide

Method 2 : Adding only water without NaOH (or KOH or LiOH)

- 2-bromo-2-methylpropane is dissolved in ethanol.
- Water is added and the mixture is heated.

The reaction is as follows, by the use of structural formulas.



2-bromo-2-methylpropane + water → 2-methylpropan-2-ol + hyrogen bromide

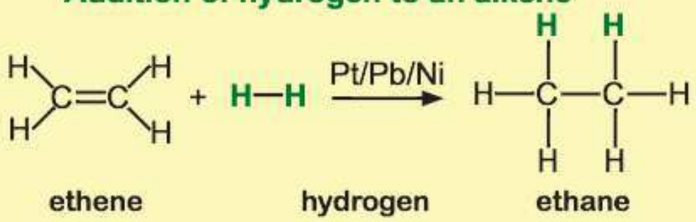
SUMMARY: ADDITION, ELIMINATION AND SUBSTITUTION REACTIONS

ADDITION REACTIONS

- The **addition** of an atom/group of atoms to a molecule.
- It occurs in unsaturated molecules of alkenes and alkynes.

Hydrogenation

Addition of hydrogen to an alkene

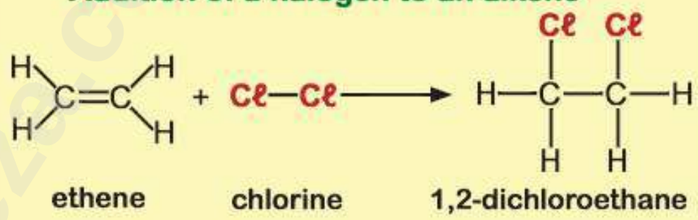


ethene + hydrogen → ethane

1. **Reactants** : Alkene (dissolved in non-polar solvent) + H_2
2. **Addition** : Two H-atoms
3. **Products** : Alkane
4. **Reaction conditions**: Pt, Pd or Ni catalyst Dissolve in non-polar solvent ($CC\ell_4$) and bubble H_2-gas into the container

Halogenation

Addition of a halogen to an alkene



ethene + chlorine → 1,2-dichloroethane

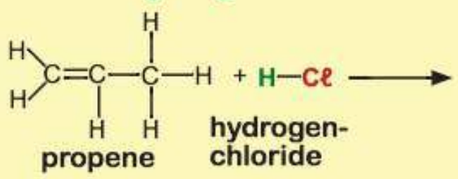
1. **Reactants** : Alkene + halogen (X_2) (X = Cℓ, Br of I)
2. **Addition** : Two identical X-atoms
3. **Products** : Haloalkane
4. **Reaction conditions**: X_2 dissolved in non-polar solvent ($CC\ell_4$). No water added.

ADDITION REACTIONS
Reactions of alkenes

Hydrogenation | Hydrohalogenation | Halogenation | Hydration

Hydrohalogenation

Addition of hydrogen halide to an alkene

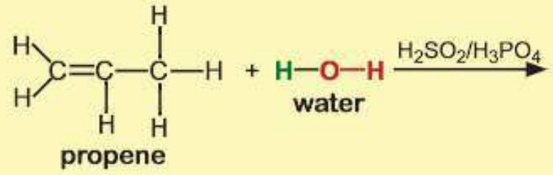


propene + hydrogen-chloride → 2-bromopropane (MAIN PRODUCT) OR 1-bromopropane (by-product)

1. **Reactants** : Alkene + hydrogen halide (HX) (X = Cℓ, Br or I)
2. **Added** : an H-atom and an X-atom
3. **Products** : Haloalkane
4. **Reaction conditions**: Anhydrous free HX. Dry HX added directly to alkene.
5. **Main product** : H-atom bonds to the C-atom which contains the most H-atoms

Hydration

Addition of water to an alkene



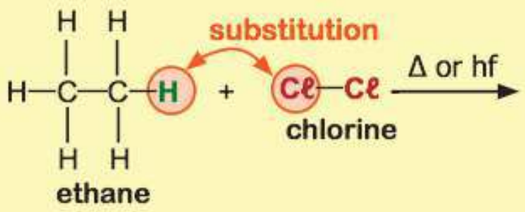
propene + water → propan-2-ol (MAIN PRODUCT) OR propan-1-ol (by-product)

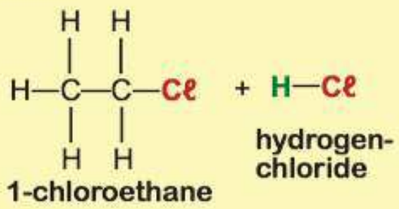
1. **Reactants** : Alkene + water
2. **Added** : OH-group and H-atom
3. **Products** : Alcohol
4. **Reaction conditions**: H_2O in excess. Small quantities (H_2SO_4 or H_3PO_4) as catalyst
5. **Main product** : H-atom bonds to the C-atom which contains the most H-atoms

SUBSTITUTION REACTIONS

- The **replacement** of an atom/group of atoms with another atom/group of atoms from **saturated** molecules of alkanes, haloalkanes and alcohols.

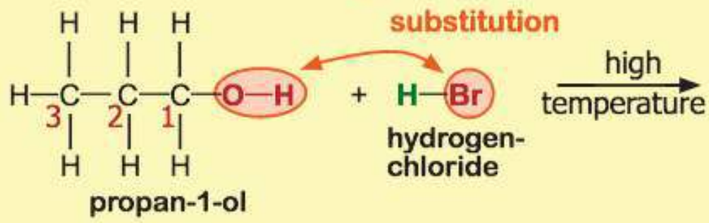
Halogenation
Alkane → Haloalkane
Reaction of a halogen with an alkane

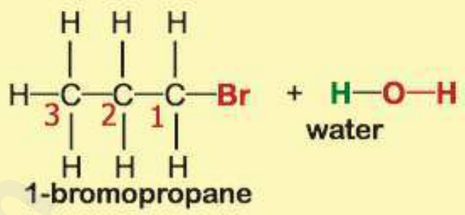




1. **Reactants** : Alkane + X_2 (X = F, Cℓ, Br or I)
2. **Substitution of** : H-atom with X-atom
3. **Products** : Haloalkane + HX
4. **Reaction conditions**: Heat or sunlight (UV-light)

Halogenation
Alcohol → Haloalkane
Reaction of a halogen with an alkohol





1. **Reactants** : Alcohol + HX (X = F, Cℓ, Br or I)
2. **Substitution of** : OH with X-atom
3. **Products** : Haloalkane + water
4. **Reaction conditions**:
   - For tertiary alcohols - HBr (or HCℓ) directly added at room temperature
   - For primary and secondary alcohols - NaBr (KBr) + H_2SO_4 used to make HBr in reaction flask. Reaction of HBr and alcohol is slow. Heat

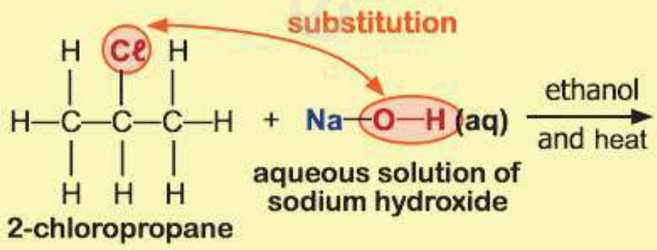
SUBSTITUTION REACTIONS

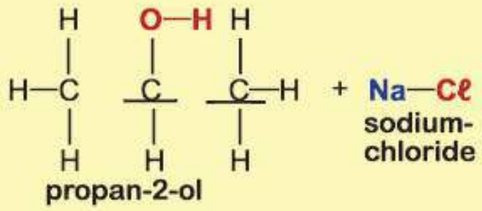
Alkane → Haloalkane (halogenation)

Alcohol → Haloalkane (halogenation)

Haloalkane → Alcohol (hydrolysis)

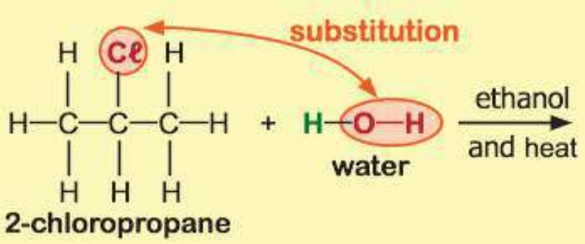
Method 1 : NaOH(aq)/KOH(aq) added
Hydrolysis
Haloalkane → Alcohol
Reaction of a haloalkane with a diluted strong base

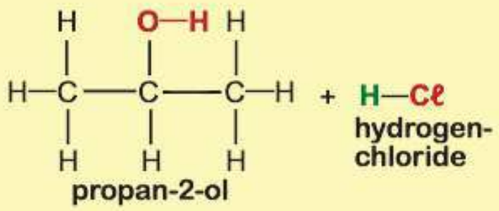




1. **Reactants** : Haloalkane + diluted strong base (NaOH/KOH/LiOH)
2. **Substitution of** : X with OH-group
3. **Products** : Alcohol + salt (NaX, KX of LiX)
4. **Reaction conditions**: Diluted strong base. Dissolve the haloalkane in ethanol. **Heat moderately**

Method 2 : With H_2O
Hydrolysis
Haloalkane → Alcohol
Reaction of a haloalkane with water

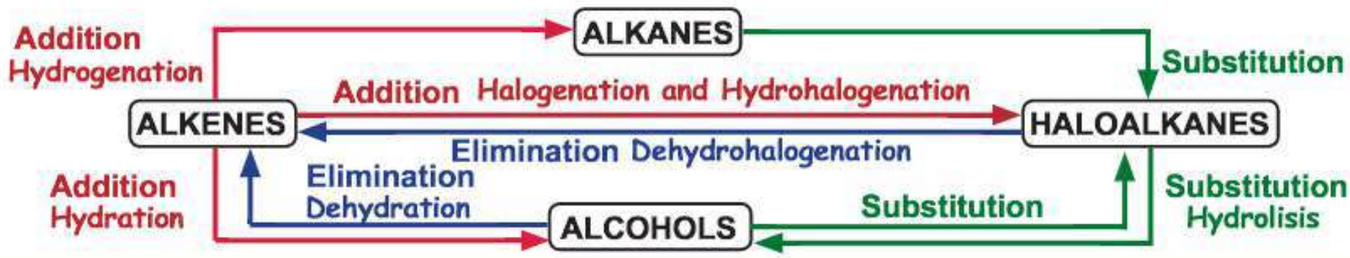




1. **Reactants** : Haloalkane + water
2. **Substitution of** : X with OH-group
3. **Products** : Alcohol + hydrogen halide (HX)
4. **Reaction conditions**: Add excess water. Dissolve the haloalkane in ethanol. **Heat moderately**

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SUMMARY: REACTIONS AT THE ALKANES, ALKENES, HALOLAKANES, ALCOHOLS AND ESTERIFICATION



REACTIONS IN ORGANIC CHEMISTRY

Reaction	Type	Reactants	Added Removed or Replaced	Products	Reaction conditions
Reactions at the ALKANES					
Combustion reaction Alkane → CO_2 + H_2O	Combustion	Alkane + O_2	Little heat added to initiate reaction	CO_2 + H_2O + energy	Sufficient O_2
Elimination reaction	Cracking	Long chain alkanes	---	Shorter alkanes and alkenes or alkene + H_2	Thermal Cracking : High temperature and pressure Catalytic Cracking: Low temperature and pressure + catalyst (Pt, Pd or Ni)
Substitution reaction Alkane → Haloalkane	Halogenation	Alkane + X_2 (X = F, Cℓ, Br or I)	Substitute a H-atom with a X-atom	Haloalkane + hydrogen halide (HX)	Sunlight (ultraviolet light) or heat
Reactions at the ALKENES					
Addition reaction Alkene → Alkane	Hydrogenation	Alkene (dissolved in non-polar soluble) + H_2	Two H-atoms added	Alkane	Pt, Pd or Ni catalyst Dissolve alkene in non-polar solvent like $CCℓ_4$ and bubble the H_2-gas into the container
Addition reaction Alkene → Haloalkane	Halogenation	Alkene + halogen (X_2) (X = Cℓ, Br or I)	Two X-atoms added	Haloalkane	X_2 dissolved in non-polar solvent $CCℓ_4$ No water added
Addition reaction Alkene → Haloalkane	Hydrohalogenation	Alkene + hydrogen halide (HX) (X = Cℓ, Br or I)	H and X-atom added	Haloalkane	Water free HX. Dry HX directly added to alkene.
Addition reaction Alkene → Alcohol	Hidration	alkene + H_2O	OH-group and H-atom are added	Alcohol	H_2O in excess Strong acid (H_2SO_4 or H_3PO_4) as catalyst
Reactions at the HALOALKANES					
Elimination reaction Haloalkane → Alkene	Dehydrohalogenation	Haloalkane + concentrated strong base (NaOH or KOH or KOH) dissolved in ethanol	X and H-atom are removed	Alkene + ionic salt + water	Dissolve base in ethanol. Concentrated strong base Strongly heated under reflux
Substitution reaction Haloalkane → alcohol	Hydrolisis	***Method 1*** Haloalkane + dilute strong base (NaOH/KOH/LiOH)	Substitute haloalkane X (X = F, Cℓ, Br or I) with a OH-group	Alcohol + ionic salt (NaX / KX / LiX)	Strong diluted base. Dissolve the haloalkane in ethanol and heat the mixture moderately
		Method 2 Haloalkane + access water	Substitute haloalkane X (X = F, Cℓ, Br or I) with a OH-group	Alcohol + hydrogen halide (HX)	Add water in excess and heat moderately Dissolve the haloalkane in ethanol
Reactions at the ALCOHOLS					
Elimination reaction Alcohol → Alkene	Dehydration	Alcohol + concentrated H_2SO_4 or H_3PO_4	OH-group and H-atom are removed	Alkene + water	Concentrated H_2SO_4 or H_3PO_4 Strongly heated
Substitution reaction Alcohol → Haloalkane	Halogenation	Alcohol + hydrogen halide (HX) (X = F, Cℓ, Br of I)	Substitute OH-group with an X-atom	Haloakane + water	• For tertiary alcohols: HBr (or HCℓ) directly added at room temperature • For primary and secondary alcohols: NaBr (KBr) + H_2SO_4 used to prepare HBr in a reaction flask. The reaction of alcohol is slow and must be heated.
Synthesis of an ESTER					
Esterification	Acid catalyzed condensation	Alcohol + carboxylic acid	removal of H and OH	Ester + water	Concentrated H_2SO_4 added as a catalyst and heated

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Exercise 12 TYPE OF REACTIONS OF ORGANIC CHEMISTRY

I. ADDITION REACTIONS

1. 1.1 What is an **addition reaction**?

_____

_____

_____

_____

1.2 Name the homologous series of which the compounds usually undergo addition. _____

1.3 Name the four types of addition reactions and also indicate for each reaction which organic reactant is converted to which organic product.

_____

_____

_____

_____

2. Name the type of addition reaction with which each of the following substances react with an alkene:

2.1 $HC\ell$: _____ 2.2 Br_2 : _____

2.3 H_2 : _____ 2.4 H_2O : _____

3. Give the complete reaction conditions required for the addition reaction where the following compounds react with an alkene.

3.1 $HC\ell$: _____

_____

3.2 H_2 : _____

_____

_____

3.3 Br_2 : _____

_____

3.4 H_2O : _____

_____

4. When H_2O and HF reacts with $CH_3CH{=}CH_2$, a **main product** and a **by-product** are formed. Markovnikov's law determines the main product and by-product

4.1 Explain Markovnikov's rule for the addition of H_2O and HF.

_____

_____

_____

_____

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4.2 Write down the condensed structure formulae for the main product that is formed according to Markovnikov rule for the addition of H_2O and HF to $CH_3CH=CH_2$. Give the name of each main product.

_____

_____

4.3 Write down the condensed structure formulae for the by product that is formed according to Markovnikov rule for the addition of H_2O and HF to $CH_3CH=CH_2$. Give the name of each by product.

_____

_____

5. For each of the following reactions, write complete balanced equations by using structural formulae. Name all th reactants and products.

5.1 The addition of hydrogen to 2-methylprop-1-ene

5.2 The chlorination of 2-methylprop-1-ene

5.3 2-methylprop-1-ene and HCℓ

5.4 2-methylprop-1-ene and water

6. Name and define the type of addition reaction that occurs in Question 5.1 to 5.4.

6.1 Question 5.1 : _____

6.2 Question 5.2 : _____

6.3 Question 5.3 : _____

6.4 Question 5.4 : _____

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4.2 Write down the condensed structure formulae for the main product that is formed according to Markovnikov's rule for the addition of H_2O and HF to $CH_3CH=CH_2$. Give the name of each main product.

_____

_____

4.3 Write down the condensed structure formulae for the by product that is formed according to Markovnikov's rule for the addition of H_2O and HF to $CH_3CH=CH_2$. Give the name of each by product.

_____

_____

5. For each of the following reactions, write complete balanced equations by using structural formulae. Name all the reactants and products.

5.1 The addition of hydrogen to 2-methylprop-1-ene

5.2 The chlorination of 2-methylprop-1-ene

5.3 2-methylprop-1-ene and HCℓ

5.4 2-methylprop-1-ene and water

6. Name and define the type of addition reaction that occurs in Question 5.1 to 5.4.

6.1 Question 5.1 : _____

6.2 Question 5.2 : _____

6.3 Question 5.3 : _____

6.4 Question 5.4 : _____

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II. ELIMINATION REACTIONS

1. 1.1 What is an **elimination reaction**?

_____

_____

_____

_____

1.2 Name the homologous series of which the compounds can undergo elimination.

_____

1.3 Name the type of elimination reaction where:

1.3.1 Larger molecules are broken down into smaller molecules. _____

1.3.2 HX eliminated out of an haloalkane. _____

1.3.3 H_2O eliminated out of an alcohol. _____

2. Give the complete reaction conditions required for the elimination reaction where :

2.1 Larger molecules are broken down into smaller molecules.

_____

_____

2.2 HX is eliminated out of an haloalkane.

_____

_____

2.3 H_2O is eliminated out of an alcohol.

_____

_____

3. For 2-chloropropane to undergo an elimination reaction an inorganic reactant is required.

3.1 Give the NAME of the inorganic reactant that is required. _____

3.2 Write down TWO reaction conditions for the reaction to take place.

_____

_____

3.3 Name the type of elimination that occurs. _____

3.4 Write a balanced equation for the reaction between 2-chloropropane and the mentioned inorganic reactant by the use of structural formulas. Also name all the reactants and products.

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4.4.1 Use structural formulae and show the chemical reaction for when 2-bromo-3-methylbutane is treated with KOH dissolved in ethanol and is strongly heated under the reflux. Give the names of all the reactants and products. Identify the main product and by-product in this reaction.

4.2 State the rule to determine which organic product will be the main product, if there is more than one possible elimination product.

_____

_____

5. In order for propan-2-ol to undergo an elimination reaction a strong inorganic acid is needed.

5.1 Give the name of the strong inorganic acid that is needed. _____

5.2 Write down TWO reaction conditions for the reaction to take place.

_____

_____

5.3 Name the type of elimination that occurs. _____

5.4 Write a balanced equation for the reaction between propan-2-ol and the inorganic acid by the use of condensed structural formulas. Also name all reactants and products.

6. 6.1 Butan-2-ol undergoes a dehydration reaction in the presence of concentrated phosphoric acid. Use structural formulas to show the chemical reaction. Give the names of all the reactants and products. Identify the main product and by-product in this reaction.

6.2 What is the role of the acid in the reaction and name any other reaction conditions.

_____

_____

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7. Cracking is a process used in the oil industry.

7.1 What is **cracking**?

_____

_____

7.2 Give one advantage of cracking for the oil industry.

_____

_____

7.3 Petrol requires molecules from the range of C_5 to C_{10}.

7.3.1 Write down the complete reaction for the catalytic cracking of $C_{15}H_{32}$ to produce C_7H_{16}. Make use of molecular formulas.

_____

7.3.2 Write down the structural formula for the products in question 7.3.1 and give the IUPAC name of each.

7.4 All cracking reactions deliver two combinations of products.

7.4.1 Name the combination of products that are the most likely products for the cracking of alkanes.

_____

7.4.2 Name the other combination of products which are possible but less likely to form during cracking of alkanes.

_____

7.5 When cracking occurs, the reaction conditions determine if thermal cracking or catalytic cracking takes place.

7.5.1 State the reaction conditions for thermal cracking.

_____

7.5.2 State the reaction conditions for catalytic cracking.

_____

7.6 Use condensed structural formulas to indicate what type of cracking reaction C_6H_{14} undergoes under conditions of high temperature and high pressure.

7.7 Use condensed structural formulas to indicate what type of cracking reaction C_2H_6 undergoes under conditions of heat and in the presence of a catalyst.

7.8 Complete the following equations for the reactions in which hexane undergoes thermal cracking (using condensed structural formulas).

7.8.1 $CH_3CH_2CH_2CH_2CH_2CH_3 \rightarrow CH_3CH_2CH_2CH_3 +$ _____

7.8.2 $CH_3CH_2CH_2CH_2CH_2CH_3 \rightarrow CH_3CHCH_2CH_2CH_2CH_3 +$ _____

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III. SUBSTITUTION REACTIONS

1. 1.1 What is a **substitution reaction**?

_____

_____

_____

_____

1.2 Name the homologous series of which the compounds can undergo substitution.

_____

2. Name the type of substitution reaction that occurs with each of the following inorganic molecules as one of the reactants:

2.1 $HC\ell$: _____ 2.2 Br_2 : _____

2.3 NaOH : _____ 2.4 H_2O : _____

3. Ethane reacts with chlorine to prepare chloroethane.

3.1 Write an equation in words for this reaction.

_____

3.2 Write down the structural formulae for this reaction.

3.3 Name ONE reaction condition required for the reaction in Question 3.1 to occur.

_____

4. 4.1 Write down the balanced equation for the reaction of 2-methylpropan-2-ol with HBr by the use of structural formulas. Name the products that are formed.

.

4.2 Is 2-methylpropan-2-ol a primary, secondary or tertiary alcohol? Explain.

_____

_____

4.3 State the reaction conditions required for the reaction of the type of alcohol in question 4.2 with HBr.

_____

5. 5.2 Write the balanced equation for the reaction of propan-2-ol with HBr by using structural formulas. Name the products formed.

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5.2 Is propan-2-ol a primary, secondary or tertiary alcohol? Explain.

_____

_____

5.3 Write the balanced equation for the reaction of pentan-1-ol with HBr by the use of condensed structure formulas. Name the products that are formed.

5.4 Is pentan-1-ol a primary, secondary or tertiary alcohol? Explain.

_____

_____

5.3 How should the HBr be prepared for the substitution reaction with the type of alcohols mentioned in Question 5.2 and 5.4 ?

_____

_____

6. 6.1 Write a balanced equation for the hydrolysis reaction which 2-bromo-3-methylbutane undergoes to form an alcohol and potassium bromide. Use structural formulas. Name the products that are formed.

6.2 State the conditions for this reaction. _____

_____

7. 7.1 Write a balanced equation for the hydrolysis reaction which 2-chloro-2-methylpropane undergoes to form an alcohol and hydrogen chloride. Use structural formulas. Name the products that are formed.

7.2 State the conditions for this reaction. _____

_____

7. Complete the following reaction for the halogenation substitution reaction of:

7.1 $CH_4 + C\ell_2 \rightarrow$

3.2 $CH_3OH + HC\ell \rightarrow$

8. Complete the hydrolisis reaction for:

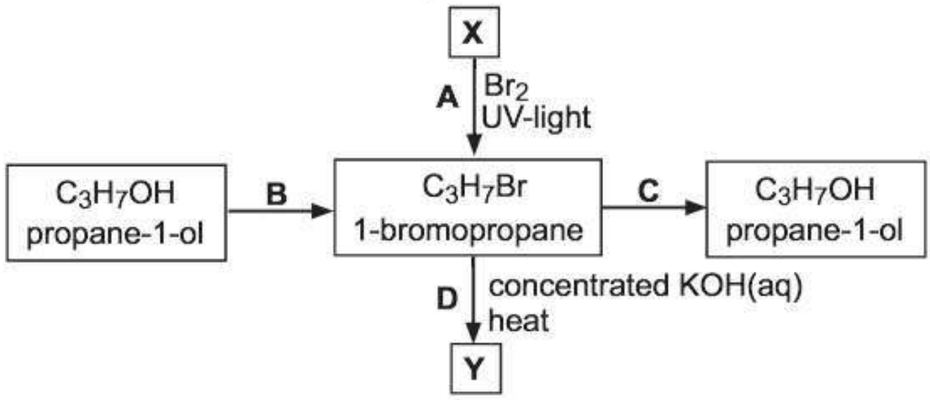
8.1 $CH_3Br + NaOH(dilute) \rightarrow$

8.2 $CH_3CH_2Br + H_2O \rightarrow$

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IV. GENERAL

1. A few organic compounds are shown in the following flow chart below.



1.1 Name the type of reaction represented by

1.1.1 **A**: _____ 1.1.2 **B**: _____

1.1.3 **C**: _____ 1.1.4 **D**: _____

1.2 Use condensed structural formulas to write a balanced equation for reaction **C**.

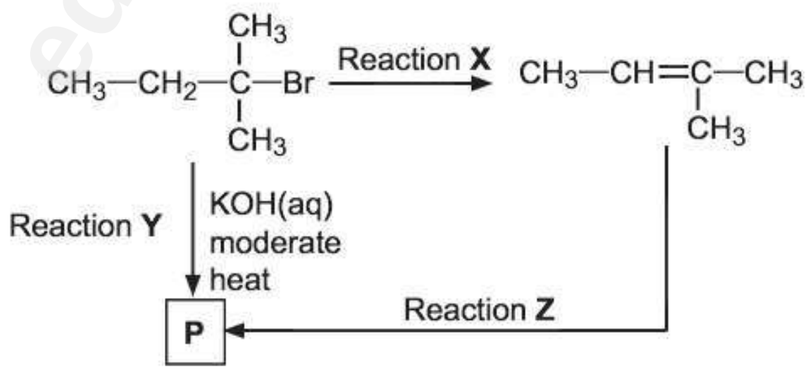
1.3 Write down the structural formula for compound **Y**.

1.4 In order to obtain product **Y**, C_3H_7Br is heated with a concentrated KOH solution under the reflux. Use condensed structural formulas to write a balanced equation for the reaction.

1.5 A group of students decided to heat C_3H_7Br with diluted sodium hydroxide instead of concentrated potassium hydroxide under reflux. Write down the IUPAC name of the organic compound that they will obtain.

_____

2. In the flow chart below **X**, **Y** and **Z** represents three different types of organic reactions.



2.1 Name the type of reaction represented by **X**. _____

2.2 Name two reaction conditions for reaction **X**. _____

_____

2.3 Reaction **Y** is a substitution reaction. Write down the structural formula for substance **P**, which is formed during this reaction.

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2.4 Apart from the organic reactant, write down the name and the formula for the other reactant needed in reaction **Z**.

_____

2.5 State the type of reaction represented by **Z**. _____

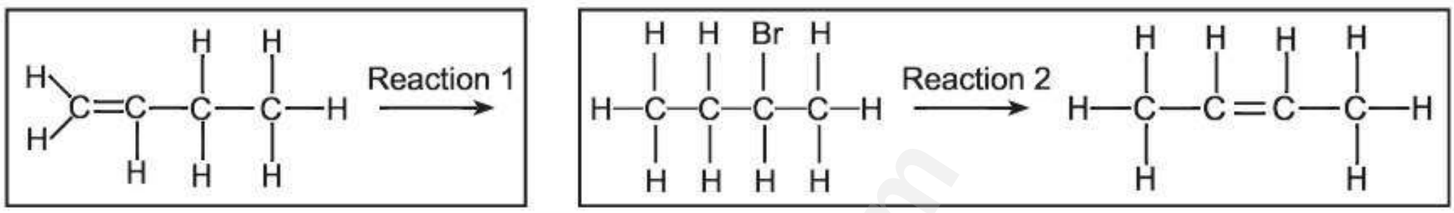
2.6 Reaction **Z** can be reversed in a elimination reaction.

2.6.1 Name the type of elimination reaction. _____

2.6.2 Give the reaction conditions required for this reaction to take place.

_____

3. John and Sarah both try to change but-1-ene to but-2-ene. Sara tried the following method:



3.1 What type of reaction is:

3.1.1 Reaction 1 (addition, substitution or elimination)? _____

3.1.2 Reaction 2 (addition, substitution or elimination)? _____

3.2 Name the other reactant that Sarah also needed to use in Reaction 1. _____

3.3 List the reaction conditions required for Reaction 2 to take place.

_____

3.4 John follows a method in which an alcohol is formed first. For this he performs an addition reaction followed by an elimination reaction.

3.4.1 Provide the name of the addition reaction to be carried out. _____

3.4.2 Provide the name of the ilimination reaction to be carried out. _____

3.5 Give the IUPAC name for the alcohol which is formed. _____

3.6 Is the alcohol in Question 3.5 a primary, secondary or tertiary alcohol? _____

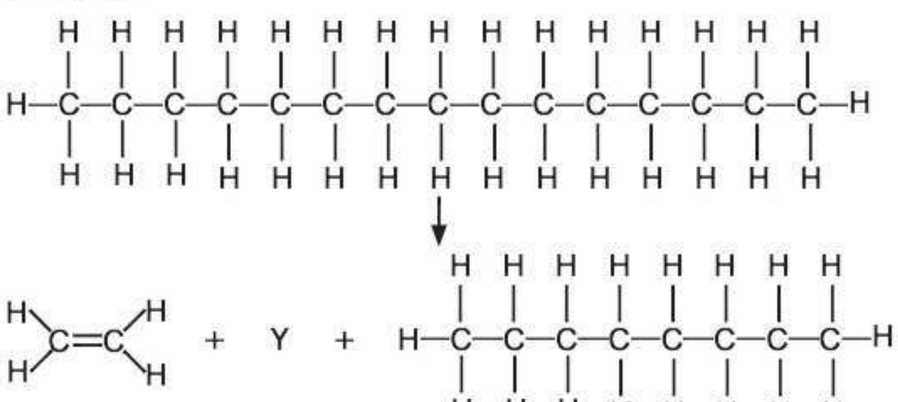
4. Cracking is a process that is currently used in the oil industry.

4.1 Define cracking.

_____

_____

4.2 Gasoline need alkanes in the range of C_5 tot C_{10}. The diagram below shows a possible thermal cracking reaction reaction of $C_{15}H_{32}$.



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4.2.1 What reaction conditions are needed for this reaction?

_____

4.2.2 Write down the structural formula and IUPAC name for the hydrocarbon represented by **Y**.

_____

4.2.3 What reaction conditions are needed for catalytic cracking?

_____

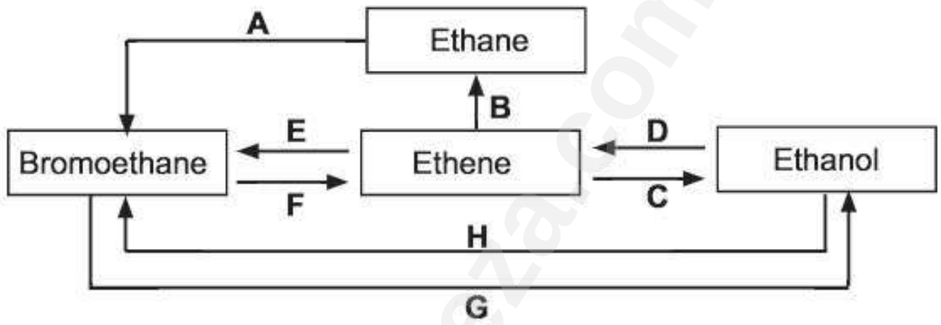
4.2.4 Name two advantages of catalytic cracking.

_____

4.2.5 Name two products of catalytic cracking.

_____

5. The following diagram shows some of the reactions ethane undergoes.



5.1 Name the type of reaction that is represented by each of the letters **A**, **B**, **D** and **H**.

A : _____ **B** : _____

D : _____ **H** : _____

5.2 Use structural formulas to write a balanced equation for reaction **B**.

5.3 In addition to ethene, which other reactant is needed for reaction **E**?

_____

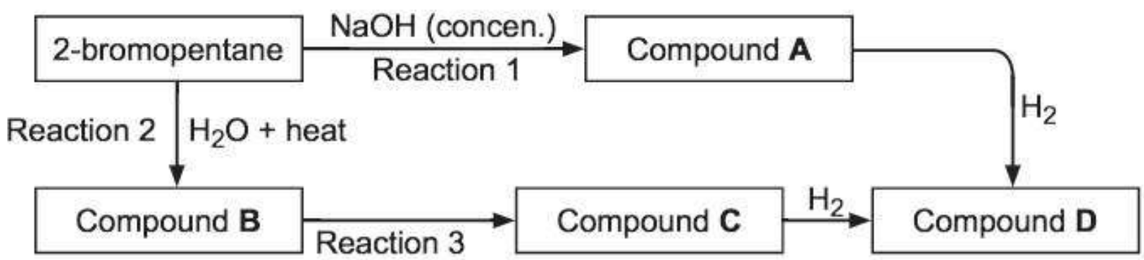
5.4 Both reactions **F** and **G** takes place in the presence of a base. Reaction **F** is an elimination reaction and **G** is a substitution reaction.

5.4.1 How does the base in reaction **F** differ from the base in reaction **G**?

_____

5.4.2 Name the type of elimination reaction represented by **F**. _____

6. The following flow chart shows how three compounds can be formed from 2-bromopentane.



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6.1 Reaction **1** takes place in the presence of concentrated sodium hydroxide. Write down:

6.1.1 Another reaction condition for this reaction.

_____

6.1.2 The name of the type of reaction that occurs. _____

6.1.3 The structural formula of Compound **A**, the main product that is formed.

6.2 In reaction **2**, the 2-bromopentane reacts in the presence of excess water when moderately heated.

6.2.1 Write down the IUPAC name of Compound **B**. _____

6.2.2 Use structural formulas to write down a balanced equation for Reaction 2 .

6.4 Reaction **3** occurs when Compound **B** is heated in the presence of concentrated sulfuric acid. Give the IUPAC name of Compound **C**, the main product that is formed.

_____

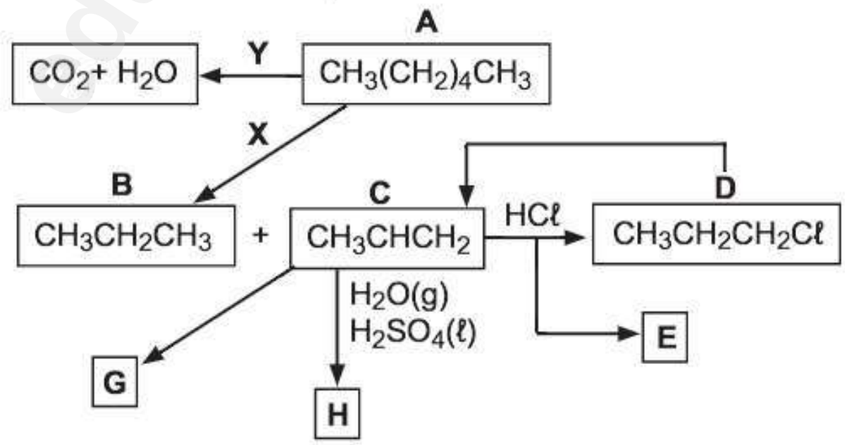
6.5 Compound **C** is heated under high pressure to form an alkane and another product.

6.5.1 Name the type of reaction that occurs. _____

6.5.2 Write the IUPAC names of all the products, of the alkane and the other product that is formed.

_____

7. Consider the following flow chart and answer the questions that follow:



7.1 Give the IUPAC names of compound:

7.1.1 **G** : _____ 7.1.2 **H** : _____

7.2 Name the type of reaction that converts **C** to **G**. _____

7.3 Compound **B** can be converted to compound **D**. List the names of the reactants which convert **B** to **D** and give the reaction conditions for this reaction to take place.

_____

_____

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7.4 Name compound **E**. _____

7.5 Name the type of reaction that converts **D** to **C** and give the reaction conditions for this reaction to take place.

_____

_____

7.6 Reaction **X** is a simple industrial process.

7.6.1 Name reaction **X**. _____

7.6.2 Explain the purpose of reaction **X**. _____

_____

7.7 Name the type of reaction that converts **C** to **H**. _____

7.8 It is said that reaction **Y** is detrimental to the environment and to humans.

7.8.1 Give ONE use of reaction **Y**.

_____

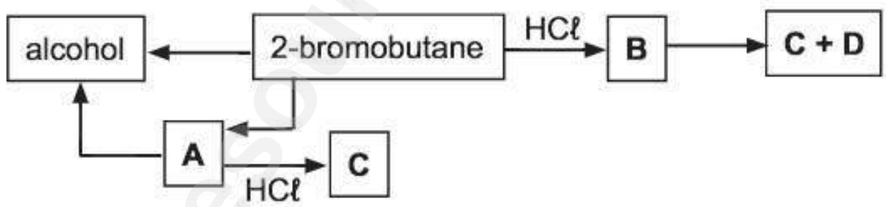
7.8.2 Give ONE negative environmental impact of reaction **Y**.

_____

7.8.3 Give ONE negative impact that reaction **Y** has on humans.

_____

8. Consider the following reactions and answer the questions that follow:



2-bromobutane undergoes an elimination reaction to form compounds **A** and **B**.

8.1 Name the type of elimination reaction. _____

8.2 Give the reaction conditions required for the reaction to take place.

_____

8.3 Draw the structural formulae for the organic products **A** and **B** and give the names of each.

8.4 Which product (**A** or **B**) in Question 8.3 is the main product? _____

2-bromobutane undergoes a reaction to form an alcohol.

8.5 Name the other reactant needed for this reaction. _____

8.6 Name the type of reaction. _____

8.7 Draw the structural formulas for the alcohol that forms.

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8.8 Write down the formula of the other product that forms. _____

8.9 Compound **A** can be converted to alcohol.

8.9.1 What conditions are needed for this reaction to take place?

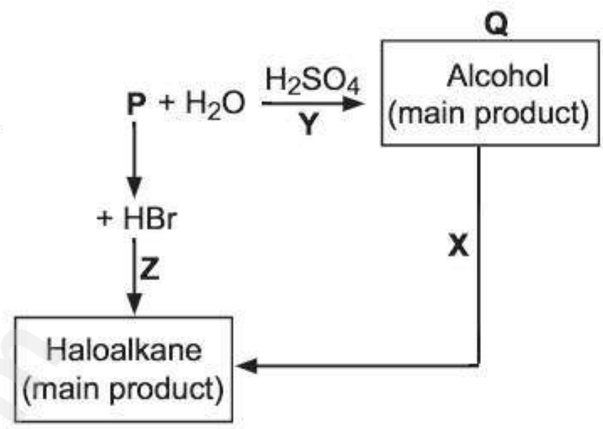
_____

8.9.2 Name the type of reaction._____

9. The flow chart shows how an alkane, represented by **P**, can be used as starting substance in the production of Compounds **R** and **Q** . **X**, **Y** and **Z** represents organic reactions.

9.1 Write down the type of addition reaction represented by:

9.1.1 **Y** : _____ 9.1.2 **Z** : _____



9.2 Write down the:

9.2.1 IUPAC name of compound **P**.

_____

9.2.2 IUPAC name of compound **R**.

_____

9.2.3 Structural formula for compound **Q**.

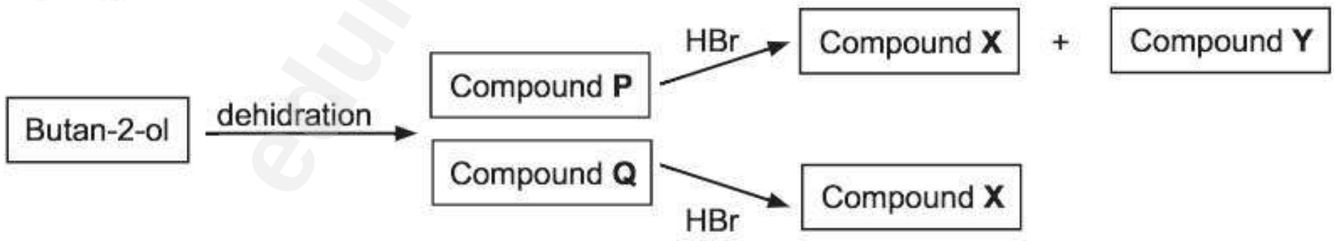
9.3 Reaction **X** represents the conversion of alcohol to a haloalkane. Write down:

9.3.1 Two reaction conditions required for this reaction. _____

_____

9.3.2 The type of reaction represented by **X**. _____

10. The following diagram shows the conversion of an alcohol into haloalkanes.



10.1 Name the type of organic reaction which dehydration is an example of. _____

10.2 What type of reaction occurs when substance **P** is converted to form Compounds **X** and **Y** as indicated above.

_____

10.3 Use structural formulas to write a balanced equation to describe the preparation of Compound **Q** as indicated above.

10.4 Will Compound **P** or **Q** be the main product? Give a reason for your answer. _____

_____

10.5 A student shows that butan-2-ol can convert directly into compound **X**.
Name the type of reaction that will take place during a direct conversion._____

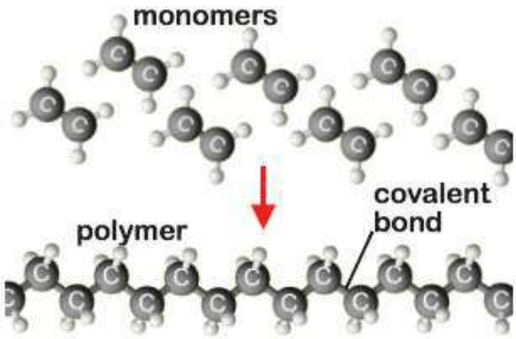
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PLASTICS AND POLYMERS

ORGANIC MACROMOLECULES

Macro means big! **A macromolecule is a molecule consisting of a large number of atoms**. Typical macromolecules consist of anything from 2,000 to 20,000 C-atoms in the main chain. A different name for a macromolecule is a **polymer molecule**. A polymer is made up of a number of **monomers**.

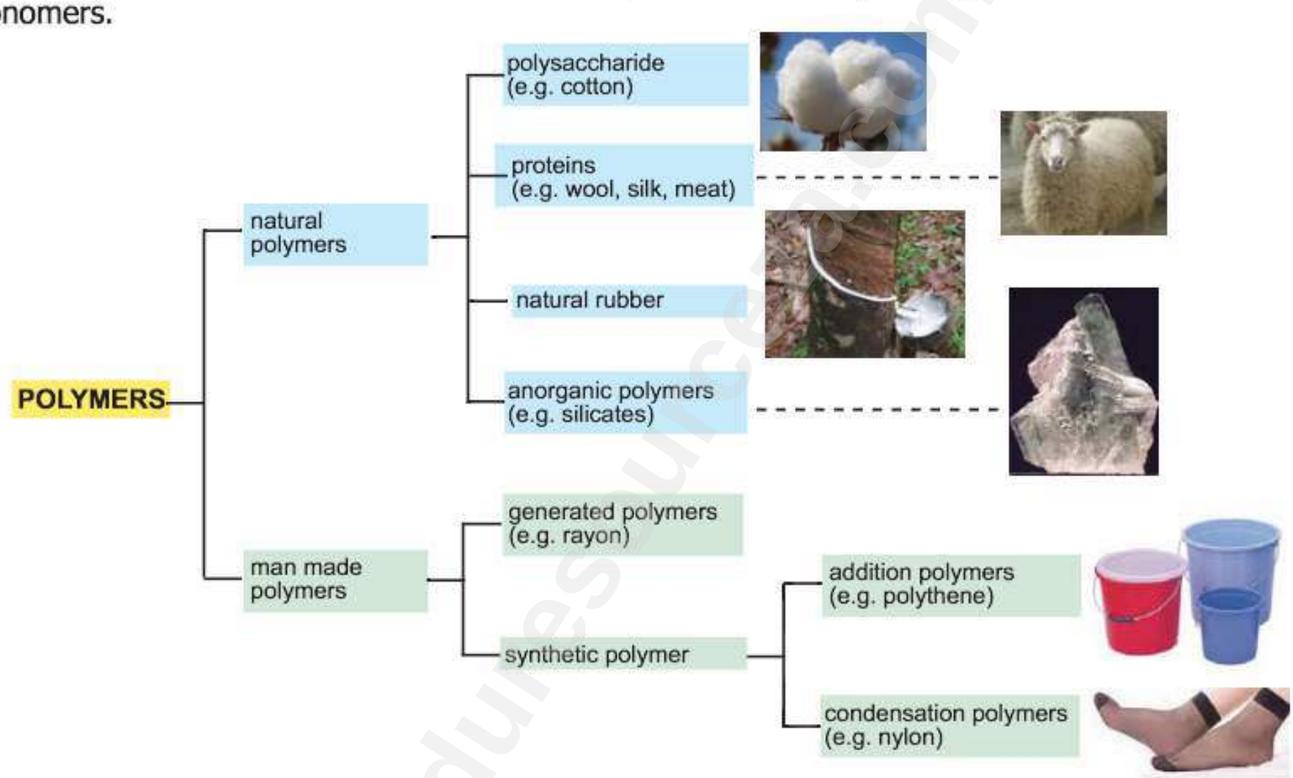
- ***A monomer is a small organic molecule that can be covalently bonded to each other in a repetitive pattern.***
- ***A polymer is a large molecule made up of smaller monomer units covalently bonded to each other in a repetitive pattern.***



The formation of a polymer from monomers.

Polymers can be natural or man-made. Living organisms contain many natural polymers such as carbohydrates and proteins. Rubber is found in natural polymer latex that is tapped from the rubber tree. Other natural polymers are wool, silk and the cellulose in wood and paper.

Man-made polymers include **generated polymers** and **synthetic polymers**. Generated polymers are made by changing natural polymers. Synthetic polymers are made in the chemical industry from the corresponding monomers.



Classification of polymers in natural and man-made polymers.

All man-made or **synthetic polymers** are considered as **plastics**. All plastics are polymers but not all polymers are plastics. For example, wool is a natural polymer, but is not a plastic.

There are about 20 main types of plastics, of which polyethylene, polyvinyl chloride (PVC), polystyrene and polyvinyl acetate (PVA) are some examples.

Many plastics are recyclable. Where they are recyclable, the symbol represented as in the figure shown right, is somewhere on the product. It is our responsibility as users of these products to ensure that they are recycled thereby reducing the burden on landfills and the environment.


The recyclability symbol.

Monomers are converted into polymers by a process called **polymerization**.

- ***Polymerization is a chemical reaction in which monomer molecules bond to form a polymer.***

During polymerization two basic polarization processes are used, namely:

- **Addition polymerization** (form addition polymers)
- **Condensation polymerization** (form condensation polymers)

ADDITION POLYMERIZATION

- ***Addition polymerization is a reaction in which small molecules bind to form very large molecules through addition at double bonds.***

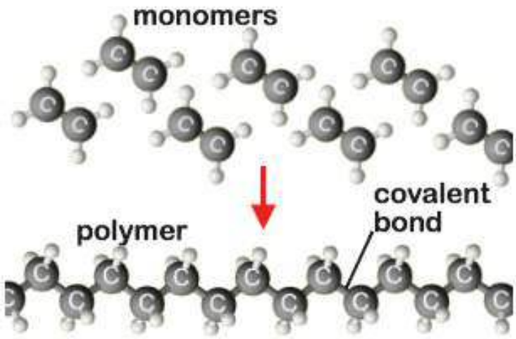
An addition reaction therefore occurs when monomers bond without any molecules or atoms being lost. Alkenes undergo addition polymerization. Under conditions of heat and high pressures and in the presence of a catalyst

PLASTICS AND POLYMERS

ORGANIC MACROMOLECULES

Macro means big! **A macromolecule is a molecule consisting of a large number of atoms**. Typical macromolecules consist of anything from 2,000 to 20,000 C-atoms in the main chain. A different name for a macromolecule is a **polymer molecule**. A polymer is made up of a number of **monomers**.

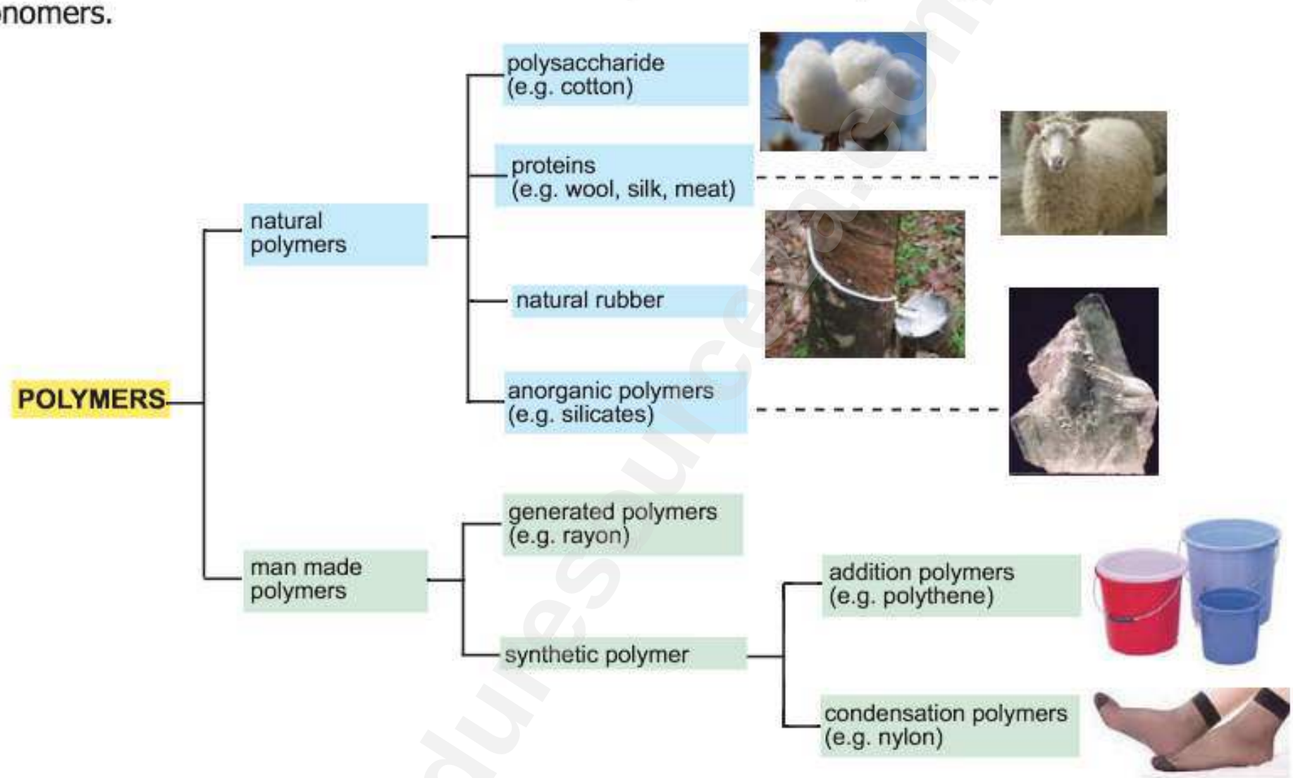
- ***A monomer is a small organic molecule that can be covalently bonded to each other in a repetitive pattern.***
- ***A polymer is a large molecule made up of smaller monomer units covalently bonded to each other in a repetitive pattern.***



The formation of a polymer from monomers.

Polymers can be natural or man-made. Living organisms contain many natural polymers such as carbohydrates and proteins. Rubber is found in natural polymer latex that is tapped from the rubber tree. Other natural polymers are wool, silk and the cellulose in wood and paper.

Man-made polymers include **generated polymers** and **synthetic polymers**. Generated polymers are made by changing natural polymers. Synthetic polymers are made in the chemical industry from the corresponding monomers.



Classification of polymers in natural and man-made polymers.

All man-made or **synthetic polymers** are considered as **plastics**. All plastics are polymers but not all polymers are plastics. For example, wool is a natural polymer, but is not a plastic.

There are about 20 main types of plastics, of which polyethylene, polyvinyl chloride (PVC), polystyrene and polyvinyl acetate (PVA) are some examples.

Many plastics are recyclable. Where they are recyclable, the symbol represented as in the figure shown right, is somewhere on the product. It is our responsibility as users of these products to ensure that they are recycled thereby reducing the burden on landfills and the environment.


The recyclability symbol.

Monomers are converted into polymers by a process called **polymerization**.

- ***Polymerization is a chemical reaction in which monomer molecules bond to form a polymer.***

During polymerization two basic polarization processes are used, namely:

- **Addition polymerization** (form addition polymers)
- **Condensation polymerization** (form condensation polymers)

ADDITION POLYMERIZATION

- ***Addition polymerization is a reaction in which small molecules bind to form very large molecules through addition at double bonds.***

An addition reaction therefore occurs when monomers bond without any molecules or atoms being lost. Alkenes undergo addition polymerization. Under conditions of heat and high pressures and in the presence of a catalyst

alkenes act as monomers and bond to form **addition polymers**. During the process, the double bonds in the alkene molecules change to single bonds.

- ***An addition polymer is a polymer formed when monomers, that usually have double bonds, bond through an addition reaction***

Addition polymers are therefore made by adding monomers together that have C=C (double) bonds (alkenes) to form very long chains that have C-C (single) bonds.

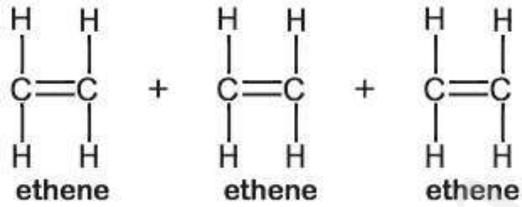
1 Polythene (polyethylene)

Polythene is one of most used plastics worldwide. The word 'polythene' literally means many alkenes. Polythene will form when **ethene** is subjected to high temperatures and high pressures. A large number of alkene molecules bind together. The number of alkene molecules in each polythene molecule ranges from 10,000 to 30,000.

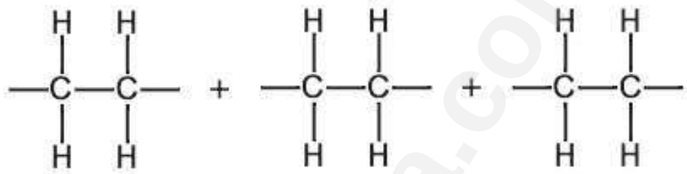
1.1 The formation of polythene (polyethylene)

Let us now look at the formation of polythene (polyethylene) and how we can deduce the formula for polythene.

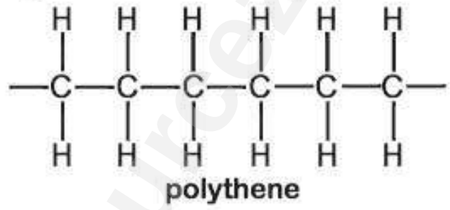
Step 1: Draw the structural formula of three or four ethene molecules down.



Step 2: Open the carbon-carbon double bonds to form single bonds.

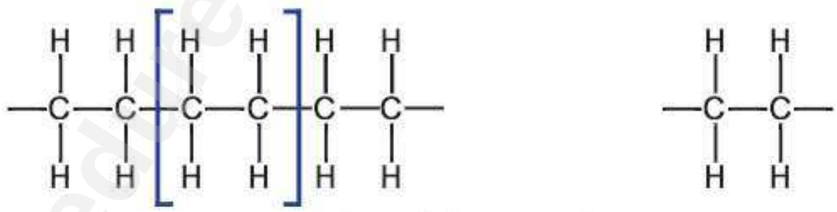


Step 3: 'Bond' the monomer molecules together to form the polymer.

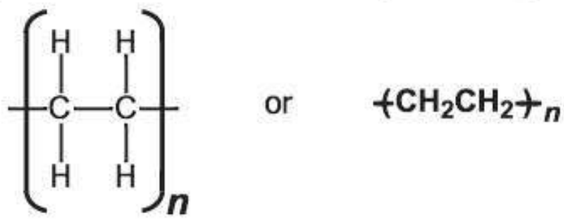


Step 4: Identify the monomer used to produce the polymer.

Once the repetitive unit is identified, the formula of the polymer can be written down.
In polythene the repetitive unit is:



The formula for polythene is as follows. A single unit (monomer of the polymer is indicated with a '**n**' below. The '**n**' means a large number and that the unit (monomer) repeats many times.

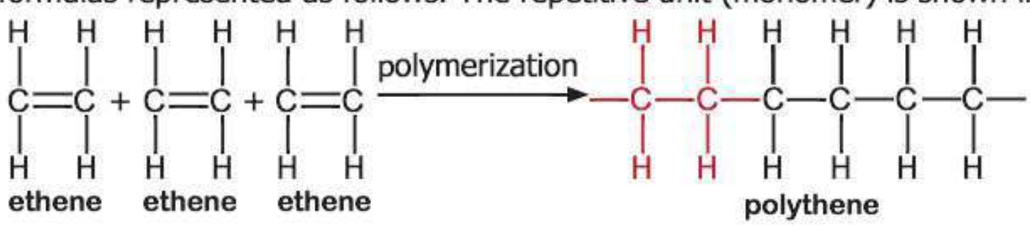


Structure formula and molecular formula of polythene.

The addition polymerization of ethene to form polythene (polyethylene) is presented by the following equation;

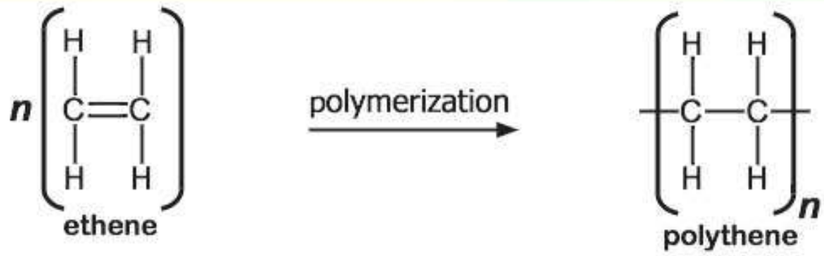


and with structural formulas represented as follows. The repetitive unit (monomer) is shown in red



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or



Polythene molecules vary in size depending on the number of ethene molecules joined together to form a specific molecule of the polymer. A Polythene plastic bag consists of a large number of different sized chains that are intertwined (like a bundle of noodles in a plate). A polythene bag can be stretched because of the tangled chains that are streached straight.

1.2 Industrial uses of polythene (polyethylene)

Depending on the reaction conditions and the type of catalyst used, **low density polyethylene (LDPE) or high density polyethylene (HDPE)** can be made.

Low density polyethylene (LDPE) has many branches on the carbon chain which prevents the chains packing close together. This reduces the intermolecular forces of attraction (induced dipole forces) between the molecules and gives them a low density.

High density polythene (HDPE) has very few branches in the carbon chain. There is better packing between the chains and the intermolecular forces of attraction (induced dipole forces) between the chains are strong giving them a high density.

1.2.1 Low density polyethylene (LDPE)

General characteristics

- Chemically unreactive (does not react with acids, bases or alcohols, nor readily with ketones, aldehydes or esters; but reacts with halogens).
- Electrical insulator
- Transparent
- Water resistant
- Lightweight but strong
- Relatively soft and pliable



The recyclability symbol for low density polyethylene. (LDPE)

Common uses



Substances made from low density polythene (polyethylene).

- Ideal for squeeze bottles because of flexibility.
- Packing materials e.g. stretch film (plastic wrap) for wrapping pallets.
- Plastic bags for sandwiches, meat, cheese, milk and fresh or frozen products.
- Flexible plastic water pipes.
- Electrical insolation of electrical wires and cables.
- Toys.



The recyclability symbol for high density polyethylene. (HDPE)

1.2.1 High density polythene (HDPE)

General characteristics

- Contains long molecular chains with few branches.
- Higher density (dense packing of chains) and higher melting point than LDPE.
- Strong and inflexible.
- High tensile strength.

Common uses

- Bottles for milk and fruit juices.
- Containers e.g. for household detergents.
- Bottles for shampoo and other hair and skin care products.
- Storage containers for food.
- Plastic crates and tanks.



Substances made of high density polythene (HDPE).

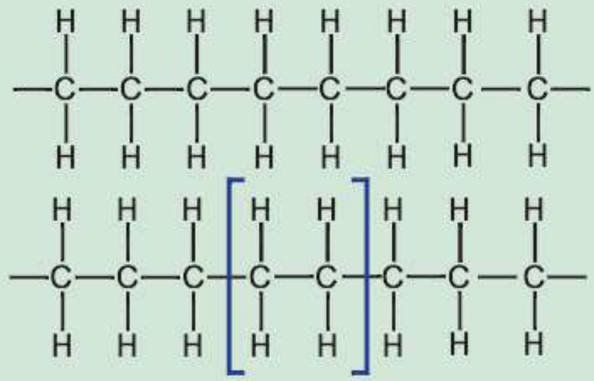
2. Identification of monomers in given addition polymers

If the structural formula of an addition polymer is given to you and you are asked to identify the monomer from which the polymer is derived, the following steps are taken:

- Find the repetitive unit and put brackets around it. Preferably choose a repetitive unit in the middle of the molecule and not on the tips, because it makes it easier.
- Separate the repetitive unit and place a double bond where necessary so that all the C-atoms of the monomer each have 4 bonds. The repetitive unit includes two C-atoms. This will give you the monomer.

Example 8

The structural formula of polythene is given here.
Identify the monomer from which polythene is derived.
Name the monomer.

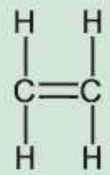


Answer:

Step 1 : Find the repetitive unit and place it between brackets.

Step 2 : Separate the repetitive unit and place a double bond so that the C-atoms in the monomer each contain 4 bonds.

Step 3 : Name the monomer.



Ethene

Monomer

4

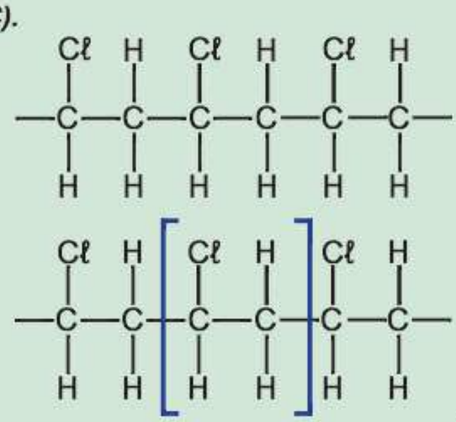
Example 9

Polyvinyl chloride (PVC) is used in the manufacturing of the following items for example.



Items made from polyvinyl chloride (PVC).

The structural formula of polyvinyl chloride (PVC) is given here.
Identify the monomer which is derived from polyvinyl chloride.
Name the monomer.

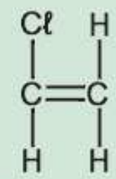


Answer:

Step 1 : Find the repetitive unit and place it between brackets.

Step 2 : Separate the repetitive unit and place a double bond so that the C-atoms in the monomer each contain 4 bonds.

Step 3 : Name the monomer.



Chloroethene

Monomer

3

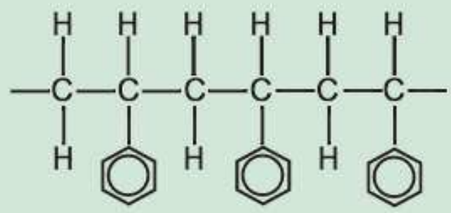
Example 10

Polystyrene (PS) is used in the manufacture of e.g. the following items.



Items made from polystyrene.

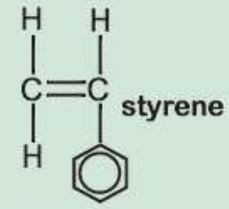
The structural formula of polystyrene is given here. Identify the monomer from which polystyrene is derived.



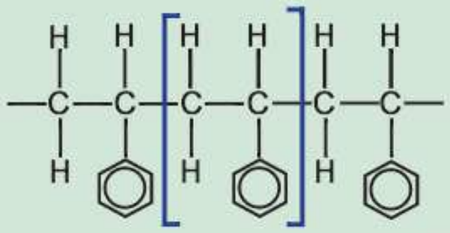
Answer:

Step 1 : Find the repetitive unit and place it between brackets.

Step 2 : Separate the repetitive unit and place a double bond so that the C-atoms in the monomer each contains 4 bonds.



Monomer



6

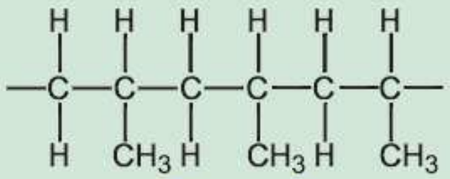
Example 11

Polypropylene (PP) is used in the manufacturing of the following items for example.



Items made from polypropylene.

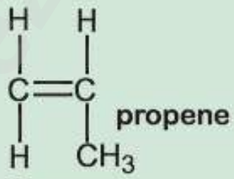
The structural formula of polypropylene is given here. Identify the monomer from polypropylene which is derived.



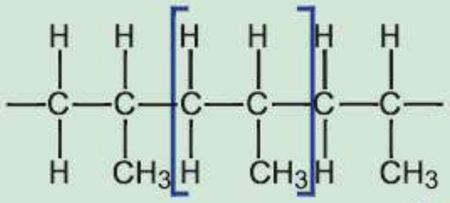
Answer:

Step 1 : Find the repetitive unit and place it between brackets.

Step 2 : Separate the repetitive unit and place a double bond so that the C-atoms in the monomer each contain 4 bonds.



Monomer



5

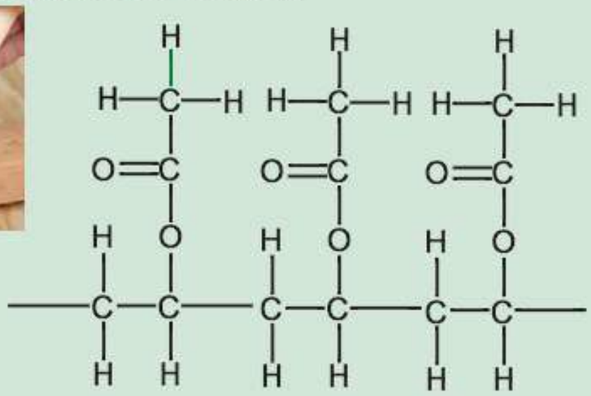
Example 12

Polyvinyl acetate (PVA) is used in the manufacturing of the following items for example.



Substances made from polyvinyl acetate

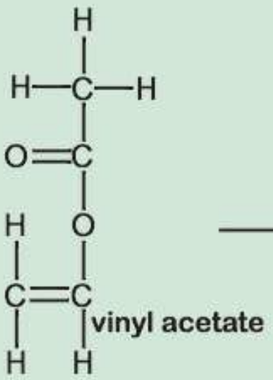
The structural formula of Polyvinyl acetate is given here. Identify the monomer from which Polyvinyl acetate is derived.



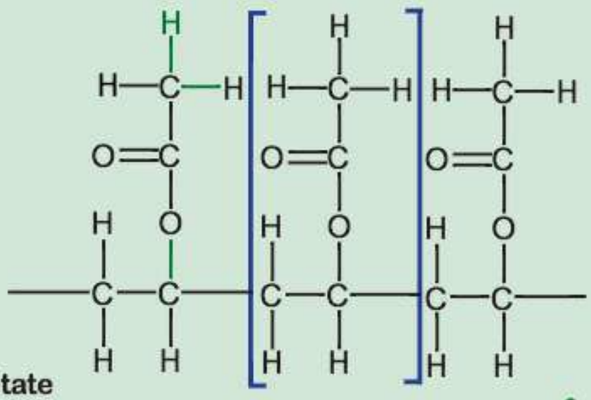
Answer:

Step 1 : Find the repetitive unit and place it between brackets.

Step 2 : Separate the repetitive unit and place a double bond so that the C-atoms in the monomer each contain 4 bonds.



Monomer

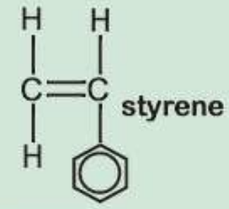


7

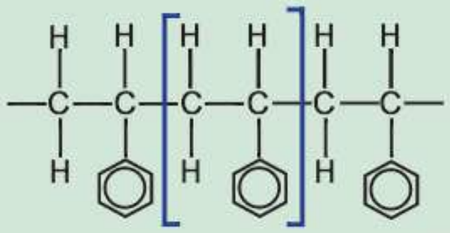
Answer:

Step 1 : Find the repetitive unit and place it between brackets.

Step 2 : Separate the repetitive unit and place a double bond so that the C-atoms in the monomer each contains 4 bonds.



Monomer



6

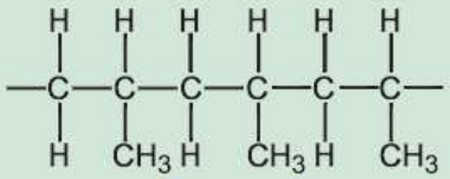
Example 11

Polypropylene (PP) is used in the manufacturing of the following items for example.



Items made from polypropylene.

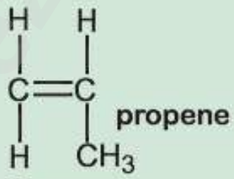
The structural formula of polypropylene is given here. Identify the monomer from polypropylene which is derived.



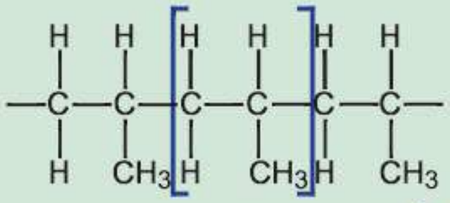
Answer:

Step 1 : Find the repetitive unit and place it between brackets.

Step 2 : Separate the repetitive unit and place a double bond so that the C-atoms in the monomer each contain 4 bonds.



Monomer



5

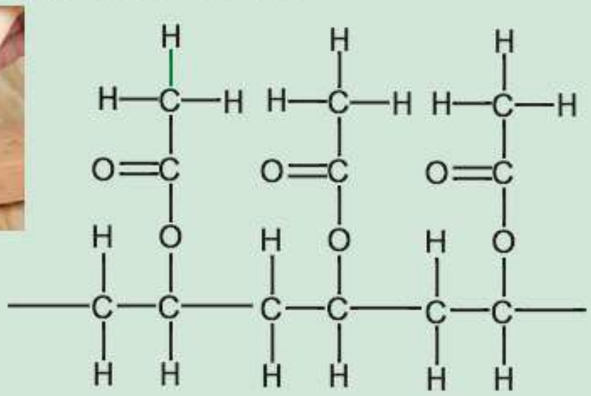
Example 12

Polyvinyl acetate (PVA) is used in the manufacturing of the following items for example.



Substances made from polyvinyl acetate

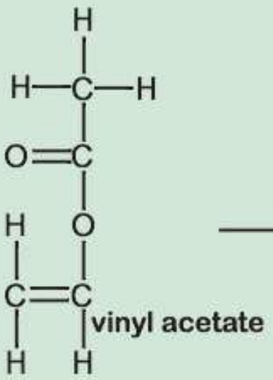
The structural formula of Polyvinyl acetate is given here. Identify the monomer from which Polyvinyl acetate is derived.



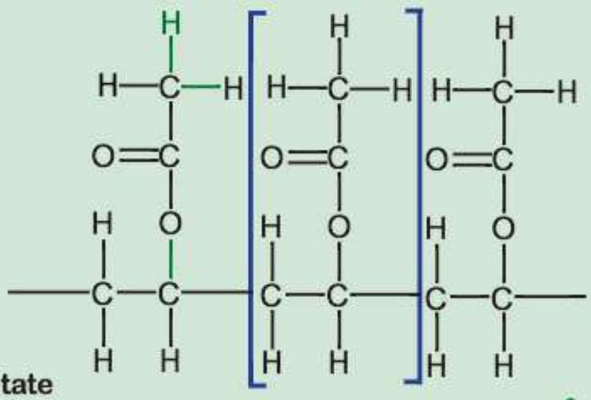
Answer:

Step 1 : Find the repetitive unit and place it between brackets.

Step 2 : Separate the repetitive unit and place a double bond so that the C-atoms in the monomer each contain 4 bonds.



Monomer



7

CONDENSATION POLYMERIZATION

- ***Condensation polymerization is a reaction in which the molecules of two monomers with different functional groups undergo condensation polymerization with the loss (elimination) of small molecules, usually water.***

Condensation polymerization occurs when two molecules react with the elimination of water molecules. The polymers that are formed by condensation polymerization are called **condensation polymerization**.

- ***A condensation polymer is 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.***

The main differences between addition polymerization and condensation polymerization is:

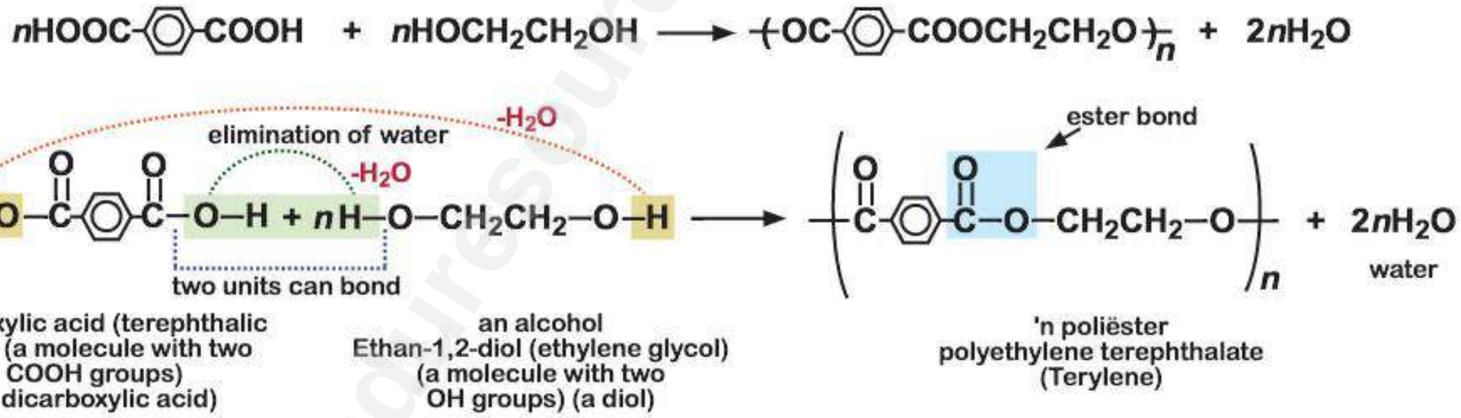
- Condensation polymers form more slowly than addition polymers.
- Water is formed in condensation polymerization and no by-products are formed in addition polymerization.
- The monomers of addition polymers contain carbon-carbon double bonds, while the monomers of condensation polymers contain functional groups, such as alcohols an carboxylic acids.

The formation of a polyester from a carboxylic acid and alcohol

When a carboxylic acid and an alcohol reacts in a esterification reaction, a water molecule is eliminated and a single ester molecule is formed, as we learnt previously in this chapter in on applications of organic chemistry. The two reactant molecules bond together to form a single ester molecule. This condensation reaction can be repeated not only to form a single ester molecule, but many esters that bond together in a long chain, a **polyester**. This is achieved by utilizing a dicarboxylic acid (an acid with two carbonyl groups, COOH, on both sides of the molecule) and a diol (an alcohol with two hydroxyl groups, OH, on both sides of the molecule).

- ***A Polyester is a substance (an alcohol) with two alcohol groups which react with a substance (a carboxylic acid) that contains two carboxylic acid groups and a condensation polymer is formed by the pairing of repetitive units of ester groups.***

For example, when the carboxylic acid terephthalic acid is heated with the alcohol ethan-1,2-diol, also called ethylene glycol, in the presence of a catalyst it forms polyester, polyethylene terephalate (PET) and water.
We write the equation as follows:



Condensation polymerization of a carboxylic acid and an alcohol form polyethylene terephthalate (PET).

Polyesters are popular synthetic fibers and can easily be spun in threads for making fabrics and garments in the clothing industry. Certain garments are made of 100% polyesters. Terylene is a polyester and artificial fiber used in making clothing, fishing line, parachutes and sleeping bags. Polyesters are wrinkle resistant and dries quickly.



Items made of polyesters.

Is also widely used for making plastic bottles for cold drinks , water, fruit juice, salad dressings, oil and household detergents. Polyesters can be successfully recycled.

The formation of polylactic acid (PLA)

Polylactic acid (PLA) is a transparent plastic (polymer) produced by the lactic acid of condensation polymerization. Water molecules are eliminated in the process.
Polylactic acid (PLA) is an interesting polymer because the monomer used to form this polymer is from plant material (renewable resources) such as corn (starch) and sugar (glucose) in contrast to other monomers that are derived from petroleum.

The monomer lactic acid, which is used to produce polylactic acid is produced by the fermentations of these plant materials. Lactic acid also occurs naturally in our bodies.



Because the resources used to make it is recyclable, rather than petroleum-based resources used for so many other plastics, it makes the acid production of polylactic acid much better for the environment. Polylactic acid is biodegradable. Polylactic acid is mainly used for packaging material and because it is biodegradable it has the potential to relieve landfill waste disposal problems. Polylactic acid has the recycling number 7.



Polylactic acid (PLA).







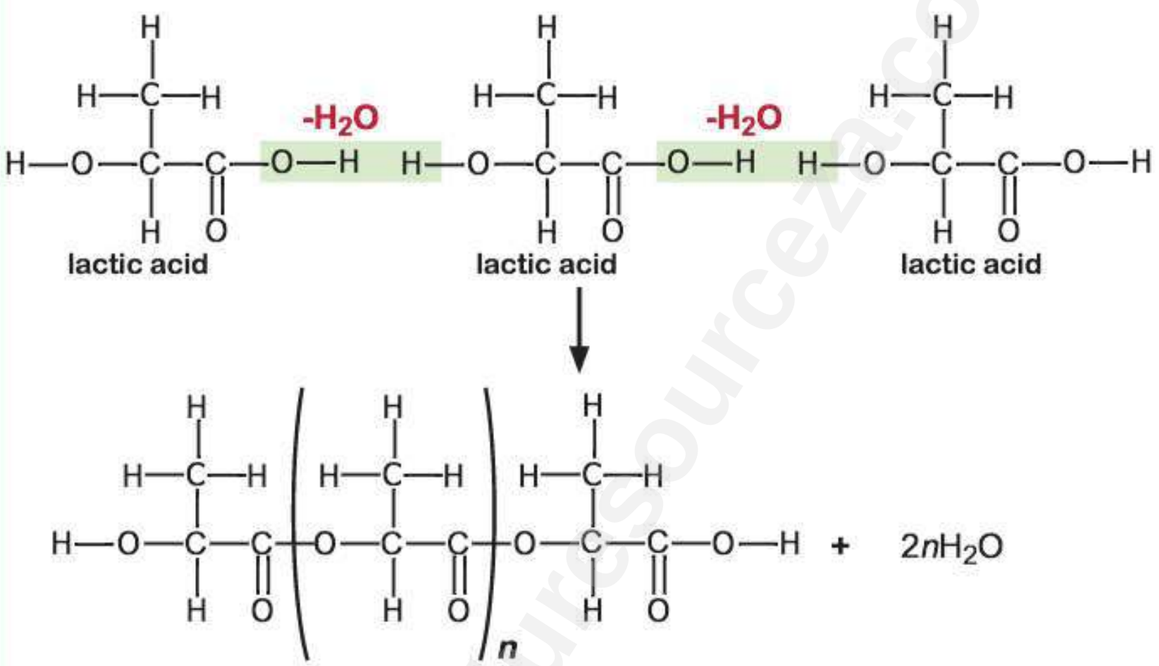
Items made from polylactic acid (PLA).

The chemical reaction that takes place to form polylactic acid (PLA) is shown below.

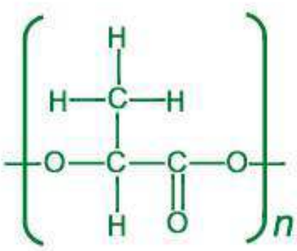
Many lactic acid molecules will react together. The elimination of water occurs and polylactic acid is formed. This is a condensation polymerization reaction because water is removed during the process and a polymer formed.

The recyclable symbol for polylactic acid (PLA).





The formation of polyethylene terephthalate (PLA).



$(H_3C_4O_2)_n$

Structural formula and molecular formula for polylactic acid (PLA).

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Identify the type of polymerization

When the structural formula of a polymer is given and you are asked to determine the type of polymerization that occurs to form the polymer, namely addition or condensation, we follow the steps below

Step 1 : Find the repetitive unit and put it in brackets.

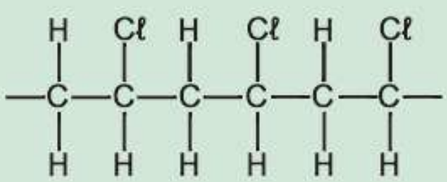
Step 2 : Isolate the repetitive unit.

Step 3 : If no additional functional groups in the repetitive unit, such as = O or OH, then the reaction was an addition polymerization reaction. Place carbon-carbon double bonds where necessary.

Step 4 : If there are additional functional groups, such as = O and -O-, then the reaction was a condensation polymerization reaction. Place a -H and an OH where necessary to replace the H_2O that was removed from the molecule.

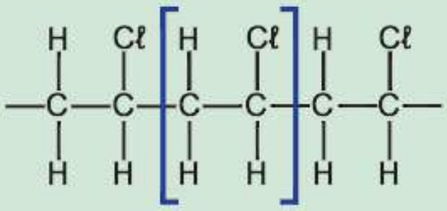
Example 13

Identify the following polymer as a result of addition or condensation.

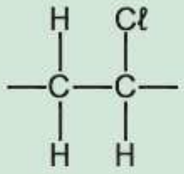


Answer:

Step 1 : Find the repetitive unit and place it between brackets.

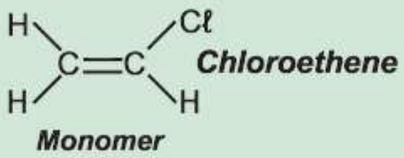


Step 2 : Isolate the repetitive unit.



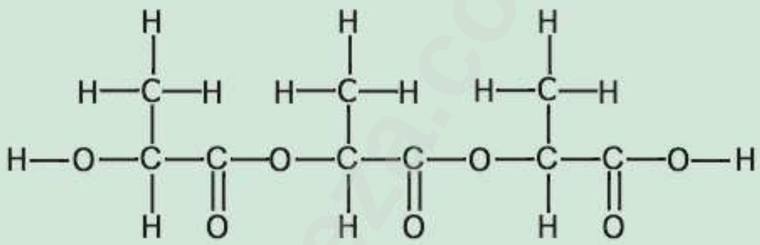
Step 3 : If there are no additional functional groups on the repetitive unit, such as = O or -O-H, then the reaction was an **addition polymerization** reaction. Place carbon-carbon double bonds where needed.

• The polymer that is given is the product of **addition polymerization**.



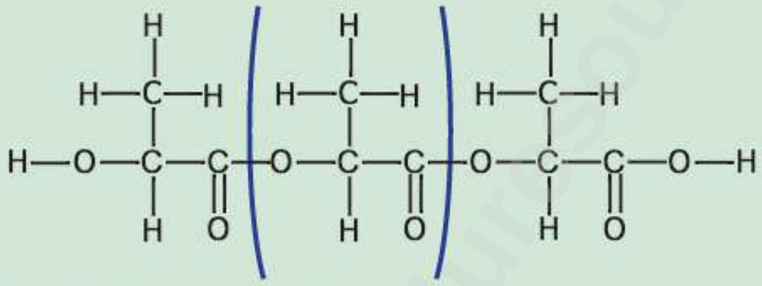
Example 14

Identify the following polymer as a result of addition or condensation polymerization

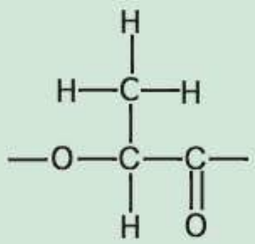


Answer:

Step 1 : Find the repetitive unit and place it between brackets.

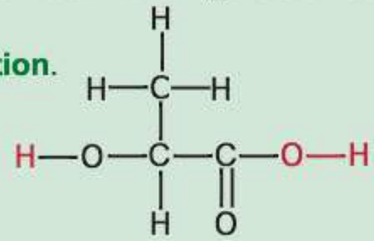


Step 2 : Isolate the repetitive unit.



Step 3 : If there are additional functional groups such as = O and -O-, then the reaction was a **condensation polymerization** reaction. Place a -H and an -O-H where necessary to return the H_2O that was removed in the molecule.

• The polymer that is given, is the product of **condensation polymerization**.



Research Task

Research one or more of the following topics:

1 Search for information and read articles on the discovery of polythene (polyethylene).
2 Development of addition polymers and build models (computer models) of addition polymers.
3 Obtain information on environmental issues related to the use of plastic.
4 Do a survey to investigate the quantities of types of fixed plastic waste generated at home or school and suggest methods to reduce this waste.
5 Find out what is Kevlar and Mylar. What is the function of this material and what is this material used for. Who discovered or invented the material. What are brake pads made of?
6 Discuss the different polymers used instead of glass.

EXPERIMENT 5

Purpose : Prepare silicon rubber by polymerization.

Method:



1. Measure approximately 20 cm^3 of sodium silicate solution in a measuring cylinder.



2. Measure approximately 10 cm^3 of ethanol in a measuring cylinder.



3. Pour the liquids together in a glass beaker.



4. Stir the mixture quickly with a mixing rod until a solid forms. (Add ethanol if necessary.)



5. Place the solid in the palm of your hand.



6. Form a ball with the solid.



7. Let the ball bounce on a tabletop or on the floor.

Chemicals required
- Sodium silicate solution
- Ethanol

Apparatus required
- Two measuring cylinders
- Glass beaker
- Mixing rod

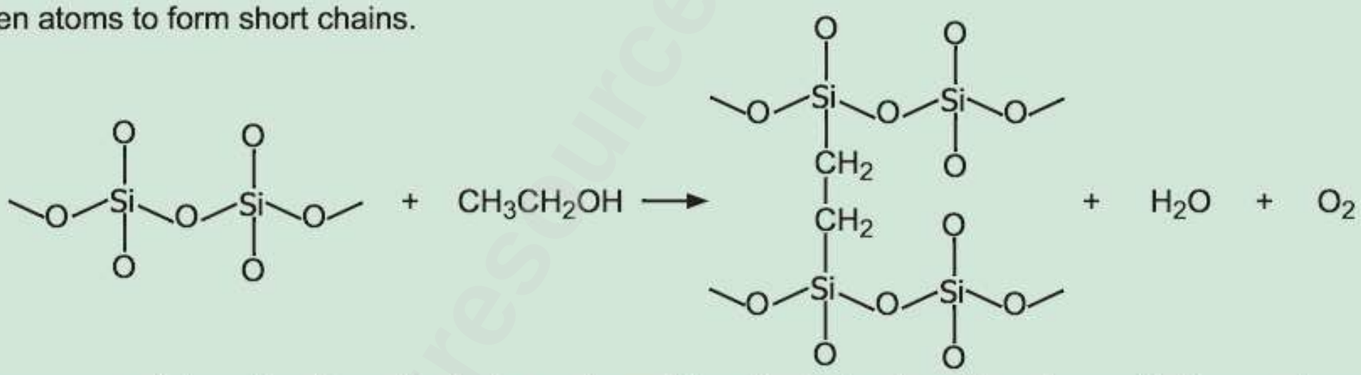
Safety!



- Wear a coat, gloves and safety glasses.
- Ethanol is flammable and toxic when it ignited.
- Sodium silicate solution irritate the skin.

Discussion and conclusion:

Silicate can, like carbon, form four covalent bonds. In sodium silicate the silicon atoms are bonded to four oxygen atoms to form short chains.



The aqueous solution of sodium silicate is a polymer. The silicate is alternating atoms of silicon and oxygen. These long chains are called the polymers. When sodium silicate and ethanol are mixed, the ethanol molecules bond to form long polymer chains. Water is eliminated during the bonding. The resulting silicon has similar physical properties to rubber.

EXPERIMENT 6

Purpose : Make plastic sulfur

Method:



1. Add a spatel yellow sulphur powder in a test tube and heat it



2. A dark jelly-like mass with high viscosity forms.



3. Heat it further until it changes into a brown liquid and boils.

Chemicals required
- Sulphur

Apparatus required
- Refractory test tube
- Test tube holder or test tube tongs
- Spatula
- Bunsen burner
- Mug with cold water

Safety!



- Wear a coat, and safety glasses.
- Work in well-ventilated room or vapor hood
- Sulphur dioxide (SO_2) is released when sulphur burns. SO_2 is irritating and toxic.

(The sulfur can catch fire and can release toxic fumes, SO_2. Extinguish the flames by covering the test tube with a cloth.)



4.Pour the brown liquid into a beaker of cold water.



5. A brown mass of plastic sulfur has formed in the water





Rhombic sulfur





Plastic sulfur

Discussion and conclusion:

Rhombic sulphur consists of rings with eight S-atoms in the crystal that is stacked on top of each other. With the first stage of heating, the rings come apart and break up into shorter chains (dark jelly-like substance). With further heating long polymer chains form. (Brown liquid that solidifies with cooling.)

EXPERIMENT 7

Purpose: To make silly putty and slime from wood glue and borax

Part 1 : 'Silly putty'

Method:











1. Add ½ cup water to ½ cup white wood glue (PVA) in a plastic bowl.
2 Add a few drops of food coloring.
3 Mix together thoroughly.

4.Make a saturated borax solution by adding a ¼ cup of water to a tablespoon of borax powder.
5 Mix thoroughly.

Chemicals required
- White wood glue
- Borax (sodium borate)
- Water
- Food coloring

Apparatus required
- Plastic cups or yoghurt holders
- Spoon or stirring rod









6. Add the borax solution to the coloured glue solution.
(Always 4 parts wood glue solution to 1 part borax solution to make silly putty).
7. Stir until a soft "putty" forms.
8. Play a little with the putty by pressing and pulling it slowly at first, then fast and hard.

Part 2 : Slime

Method:











1. Pour a ½ cup water and ½ cup white wood glue (PVA) together in a plastic cup.
2. Add a few drops of food coloring.
3. Mix together thoroughly.

4. Make a saturated borax solution by adding 1 cup of water to a heaped tablespoon borax powder in an empty beverage container.
5. Mix together thoroughly.

Chemicals required
- White wood glue
- Borax (sodium borate)
- Water
- Food coloring

Apparatus required
- Two plastic cups or yoghurt holders
- Empty plastic cooling drink bottle
- Spoon or stirring rod





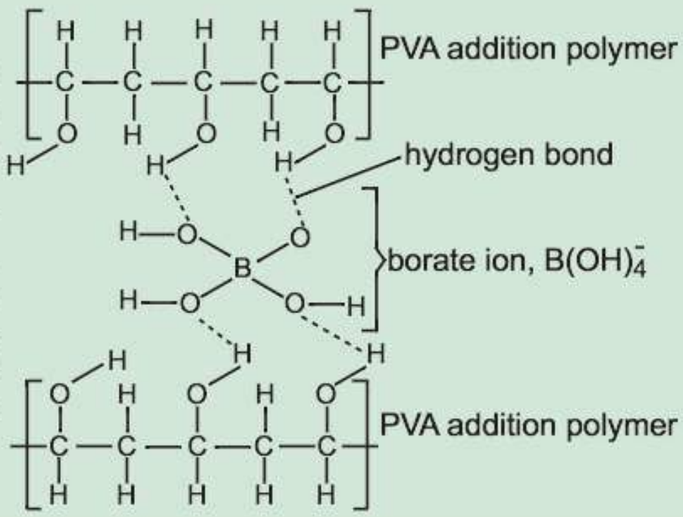


6. Add the borax solution to the, colored glue solution.
7. Stir until a soft slime is formed.
8. Remove the slime from the cup. Knead slightly and play.

Discussion and conclusion:

Wood glue contains Polyvinyl alcohol (PVA), the addition polymer of ethanol. Sodium borate (borax) is the borate ion solution. Cross bonds form between the chains, as shown to the right.

There are covalent bonds between the atoms in the polymer chains and hydrogen bonds between the polymer chains. The latter can easily be broken. When small amounts of stress is exercised on the slime or putty it breaks the H-bonds and the chains slide over each other and the slime or putty becomes liquid. When it is handled fast or hard it breaks in pieces.



Exercise 13 PLASTICS AND POLYMERS

1. Describe the following terms:

1.1 Makro molekule : _____

1.2 Monomer : _____

_____

1.3 Polymer: _____

_____

1.4 Polymerization: _____

_____

1.5 Addition polymerization : _____

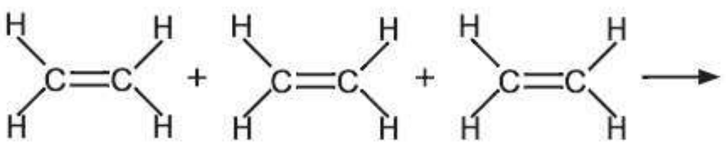
_____

1.6 Addition polymer : _____

_____

2. Alkenes, such as ethene can form polymers.

2.1 Complete the following to show how the molecules bind to form a polymer.



2.2 Provide the name of the polymer formed from ethene. _____

2.3 Write a general equation for the polymerization of ethene to form the polymer in question 2.2 above.

2.4 List five general industrial uses of the polymer in question 2.2 above.

_____

_____

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2.5 Give one major problem caused due to the everyday use of these polymer.

_____

3. Consider the following polymerization reaction.

$$n(CH_3-CH=CH_2) + \text{activator} \rightarrow \text{activator} + (-CH(CH_3)-CH_2)_n$$

3.1 Provide the name of the monomer. _____

3.2 Provide the name of the polymer. _____

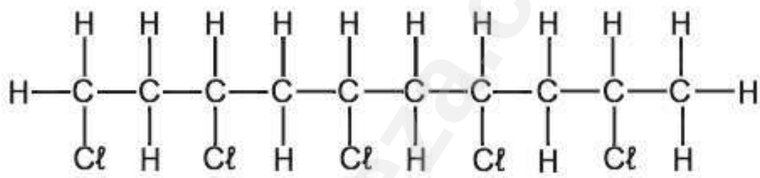
3.3 What type of polymerization occurred? _____

3.4 Give two reasons for your answer to Question 3.3.

_____

_____

4. The structure of an addition polymer is shown here.



4.1 What is an addition polymer? _____

_____

4.2 Give the structure of the repetitive unit which forms this polymer.

4.3 Give the name the structure of the monomer from which this polymer is made.

4.4 This polymer in the form of a resin is used to manufacture pipes for municipal and industrial applications. Give ONE advantage of using these materials to replace metal pipes.

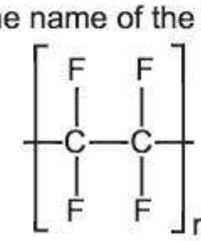
_____.

5. In 1939, the chemist, Dr. Roy Plunkett opened the valve of a new cylinder with tetrafluoro ethane gas (TFE). No gas came out. When he and his assistant opened the cylinder, they found that the gas changed in a white wax like solid. This white substance was poly tetra fluoro ethylene (PTFE), also known as Teflon. Teflon is used as the non-stick layer in cookware like frying pans and saucepans and can withstand high temperatures.



1938 the discovery of Teflon

The structure of this polymer is as follows. Draw the structure of the monomer and give the name of the monomer.



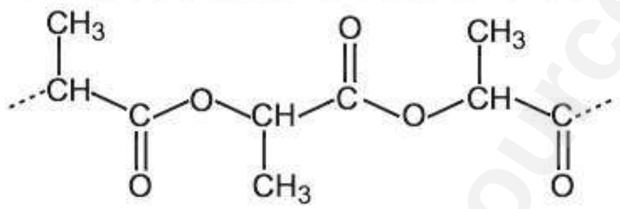
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6. Distinguish between addition polymerization and condensation polymerization.

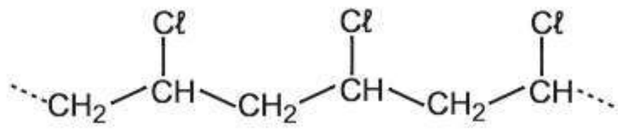
7. Distinguish between an addition polymer and a condensation polymer.

8. 8.1 Draw and label the structures of the monomers for each of the following polymers:

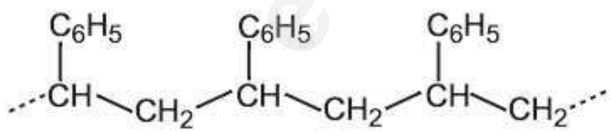
A



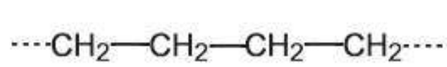
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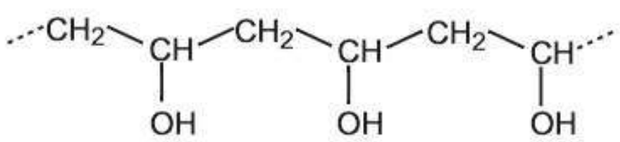
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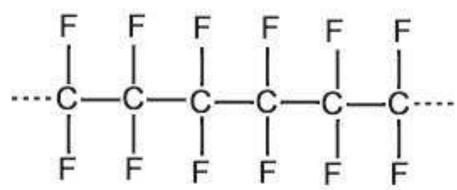
D



E



F



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8.2 Identify which polymer is:

8.2.1 polyvinyl alcohol: _____ 8.2.2 polystyrene: _____

8.2.3 polytetrafluoroethylene (Teflon): _____ 8.2.4 polypropylene: _____

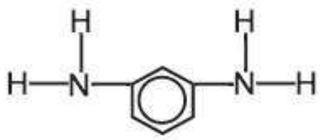
8.2.5 polyvinyl chloride: _____ 8.2.6 polylactic acid: _____

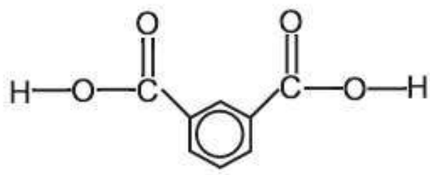
8.3 Which of these polymers is/are the result of addition polymerization? _____

8.4 Which of these polymers is the result of condensation polymerization? _____

9. Kevlar is a type of polymer that offer great resistance to tear. It is used in the manufacturing motorcycle overalls, bulletproof vests and brake pads. The following two monomers form Kevlar.







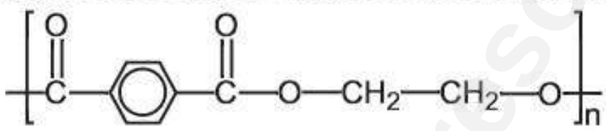
9.1 Is Kevlar an addition or condensation polymer? _____

9.2 Draw the repetitive unit of the polymer Kevlar.

9.3 What other inorganic product formed when the two monomers react to form the polymer?

_____

You are probably familiar with Mylar, a polyester film type, used in the manufacturing shiny helium balloons, awnings, space blankets and protective plastic insulators. The following monomer form Mylar.



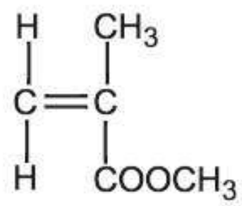




9.4 Is Mylar an addition or condensation polymer? _____

10. During hip replacements operations, a new hip is put in place with the use of bone cement, a synthetic polymer formed from the monomer methyl methacrylate. The structure is given on the right.

10.1 Draw the polymer portion, show three monomers.





10.2 What type of polymerization reaction takes place to form this polymer? _____

10.3 This type of polymer is a synthetic polymer. Describe the difference between synthetic and natural polymers.

Give two examples of natural polymers.

_____

_____

_____

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THEORY & WORKBOOK

GRADE 12

PHYSICAL SCIENCES

ORGANIC CHEMISTRY



CAPS CURRICULUM- AND ASSESSMENT POLICY STATEMENT

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BOOK 2 Part 1

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