

CAIE Chemistry A-level

13: An Introduction to AS Level Organic Chemistry Notes

This work by [PMT Education](https://www.pmt.education) is licensed under [CC BY-NC-ND 4.0](https://creativecommons.org/licenses/by-nc-nd/4.0/)



Formulae, Functional Groups and Naming of Organic Compounds

Hydrocarbons are compounds made up of only carbon and hydrogen atoms. **Alkanes** are a family of simple hydrocarbons with no **functional group**.

Naming organic compounds is something that you must be comfortable with in order to understand the rest of organic chemistry. You are required to be able to name organic compounds which have up to **6 carbons in a chain**.

Carbons in chain	1	2	3	4	5	6
Prefix	meth-	eth-	prop-	but-	pent-	hex-

There are different ways in which an organic compound can be displayed:

- **Molecular formula** - actual number of atoms of each element in a molecule.
- **Structural formula** - shows the structure carbon by carbon with hydrogens and functional groups attached.
- **Skeletal formula** - only shows the bonds on the carbon skeleton. The carbon and hydrogen atoms are not shown but any functional groups are. It can be used to simplify large complicated structures.
- **Displayed formula** - shows how all the atoms are arranged and shows every bond between them.




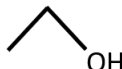
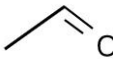

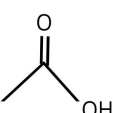
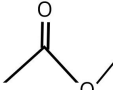
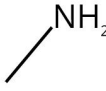

Examples of these different types of formula can be seen in the table on the following page.

A **homologous series** is a group of compounds with the same **functional group**, and with successive members differing by $-\text{CH}_2$. The functional group dictates how the compound will react.

Table 1 shows the different types of homologous series you are expected to be able to name compounds from.



Table 1: Aliphatic Compounds

Homologous series	Prefix or suffix	Example name	Example molecular formula	Example structural formula	Example skeletal formula	Example displayed formula
Alkanes	-ane	Propane	C_3H_8	$CH_3CH_2CH_3$		$\begin{array}{c} H & H & H \\ & & \\ H-C & -C & -C-H \\ & & \\ H & H & H \end{array}$
Alkenes	-ene	Ethene	C_2H_4	CH_2CH_2		$\begin{array}{c} H & & H \\ & \backslash & / \\ & C=C & \\ & / & \backslash \\ H & & H \end{array}$
Halogenoalkanes	Fluoro- Chloro- Bromo- Iodo-	Chloroethane	C_2H_5Cl	CH_3CH_2Cl		$\begin{array}{c} H & Cl \\ & \\ H-C & -C-H \\ & \\ H & H \end{array}$
Alcohols	-ol	Ethanol	C_2H_6O	CH_3CH_2OH		$\begin{array}{c} H & OH \\ & \\ H-C & -C-H \\ & \\ H & H \end{array}$
Aldehydes	-al	Ethanal	C_2H_4O	CH_3CHO		$\begin{array}{c} O & H \\ & \\ H-C & -C-H \\ & \\ H & H \end{array}$
Ketones	-one	Propanone	C_3H_6O	CH_3COCH_3		$\begin{array}{c} H & OH \\ & \\ H-C & -C & -C-H \\ & & \\ H & O & H \end{array}$
Carboxylic acids	-oic acid	Ethanoic acid	$C_2H_4O_2$	CH_3COOH		$\begin{array}{c} H & O \\ & \\ H-C & -C \\ & \\ H & O-H \end{array}$
Esters	Alkyl- -oate	Methyl ethanoate	$C_3H_6O_2$	CH_3COOCH_3		$\begin{array}{c} H & O & H \\ & & \\ H-C & -C & -O-C-H \\ & & \\ H & & H \end{array}$
Amines	-amine	methylamine	CH_5N	CH_3NH_2		$\begin{array}{c} H & & H \\ & & \\ H-C & -N & -H \\ & & \\ H & & H \end{array}$
Nitriles	-nitrile	Ethane nitrile	C_2H_3N	CH_3CN		$\begin{array}{c} H \\ \\ H-C & -C \equiv N \\ \\ H \end{array}$



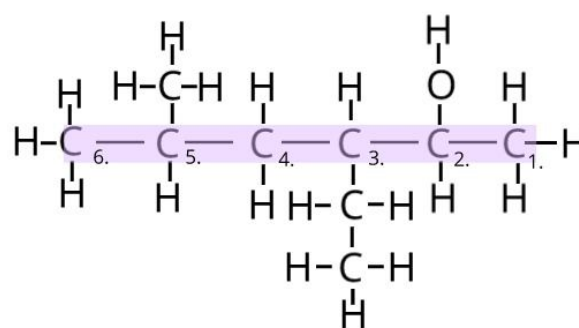
Naming Organic Compounds

Follow these rules when naming organic compounds:

1. Identify the **longest carbon chain** that contains the functional group.
2. Identify the **functional group** on the chain. This gives you the suffix or prefix of the compound.
3. Count along the carbon chain so that the **functional group has the lowest number**. See the example below to illustrate this.
4. If there are any **side chains**, add these as **prefixes** (e.g. methyl-) to the beginning of the name. Do the same if there are other (less important) functional groups. Put these at the start of the name in **alphabetical order**.
5. If there are **two or more identical functional groups** or side chains use the prefixes di-, tri- and tetra- before that section of the name.

Example:

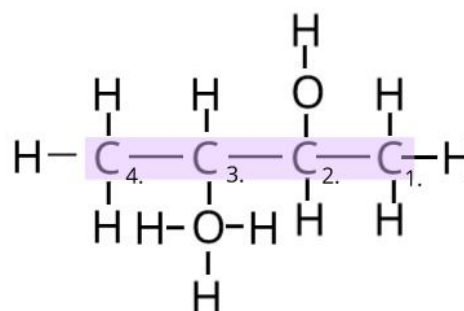
1. The longest carbon chain is **6 carbons long** so the prefix is hex-.
2. The most important functional group on the chain is the **-OH alcohol**. The suffix is therefore -ol.
3. The alcohol is on **the second carbon** in the chain (count from the side closest to this functional group). The suffix becomes **-2-ol**.



4. There are **two side chains**:
 An ethyl on the third carbon: 3-ethyl
 A methyl on the fifth carbon: 5-methyl
5. Place the prefixes in alphabetical order and add them to the name:
3-ethyl-5-methylhexanol.

Example 2:

1. This chain is **symmetrical** so it does not matter which way the carbons are numbered.
 Prefix: but-
2. There are **two alcohol groups** on the second and third carbon: -2,3-diol.
3. There are no other groups so the overall name is: **butan-2,3-diol**.



Characteristic Organic Reactions Terminology

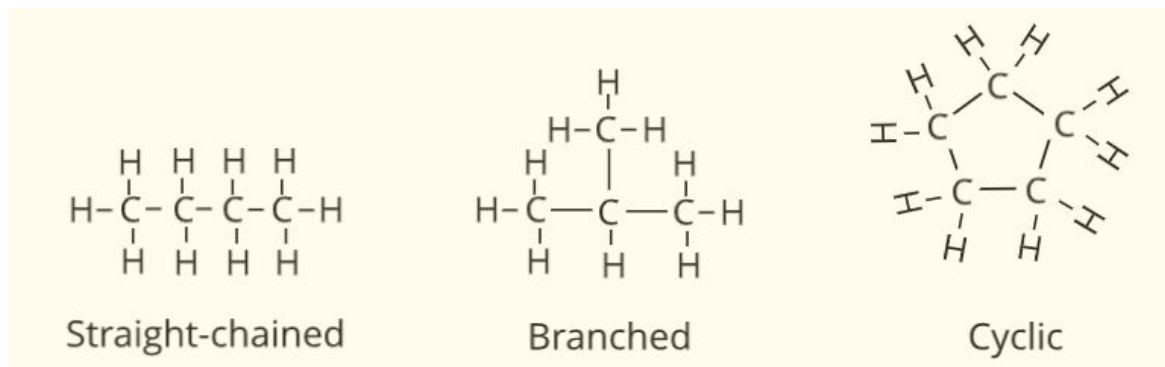
The following terms are important in organic chemistry so you must make sure you are familiar with them:

- **Functional group:** A group of atoms responsible for the characteristic reactions of an organic compound.
- **Saturated:** Containing the most amount of hydrogen atoms possible without a double or triple carbon-carbon bond.
- **Unsaturated:** Contains a carbon-carbon double or triple bond meaning it doesn't contain the greatest possible amount of hydrogen atoms.
- **Homolytic fission:** The splitting of a covalent bond where each atom retains one electron from the bonding pair.
- **Heterolytic fission:** The splitting of a covalent bond where one atom retains both electrons from the bonding pair.
- **Free radical:** An uncharged molecule with an unpaired electron.
- **Initiation:** An initial chemical reaction which triggers further reactions.
- **Propagation:** A secondary reaction where there is no net gain or loss of free radicals.
- **Termination:** The final step in a chain reaction where a reactive intermediate is rendered inactive.
- **Nucleophile:** A molecule or substance that donates electrons.
- **Electrophile:** A molecule or substance that acts as an electron pair acceptor.
- **Addition:** A reaction where two or more molecules react together to form a larger molecule.
- **Substitution:** A reaction where an atom or group is replaced by another atom or group.
- **Elimination:** A reaction in which two substituents are removed from a molecule in a mechanism with one or two steps.
- **Hydrolysis:** The splitting up of a compound or molecule using water.
- **Condensation:** The formation of a compound with the release of water.
- **Oxidation:** The loss of electrons.
- **Reduction:** The gain of electrons.

Shapes of Organic Molecules

Organic compounds can be described as being straight-chained, branched or cyclic, depending on how the carbon atoms are arranged.





Hybridisation

Hybridisation is the concept of forming **new orbitals** by combining pre-existing electron orbitals. There are various types of hybridisation:

Hybridisation of carbon: Carbon has the electron configuration $1s^2 2s^2 2p^2$. However, if the right amount of energy is provided, an electron can be promoted from one of the s orbitals to a p orbital. The configuration would now be $1s^2 2s^1 2p^3$. This is a **favourable** process due to the fact that the electrons are unpaired so there is less repulsion and more stability.

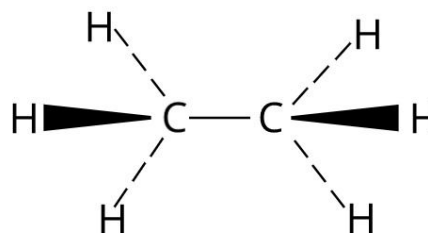
sp hybridisation - One s orbital and one p orbital **hybridise** (combine) to form two equivalent orbitals. The new orbitals are called sp orbitals and they repel to give a linear shape with a 180° bond angle.

sp² hybridisation - One s orbital and two p orbitals **hybridise** to form three equivalent orbitals. The remaining 2p orbital is left unchanged. The three new sp² orbitals all repel to give a trigonal planar arrangement with a bond angle of 120° . The unchanged 2p orbital lies perpendicular to this planar arrangement.

sp³ hybridisation - One s orbital and three p orbitals **hybridise** to form four equivalent orbitals. The new orbitals are called sp³ orbitals and they all repel to give a tetrahedral arrangement. This means the molecule has bond angles of 109.5° .

Bonding in Ethane (sp³)

An sp³ orbital overlaps with another sp³ orbital to form a C-C covalent bond. The other three orbitals overlap with the s orbital of a hydrogen atom to form more covalent bonds. These bonds between each atom are **sigma (σ) bonds**. The shape of an ethane molecule (seen on the right) is **tetrahedral**, with bond angles of **109.5°** .

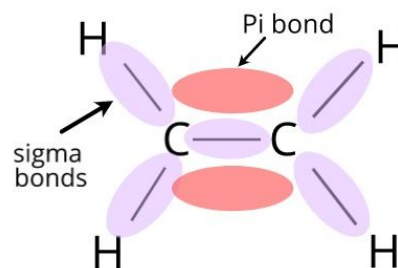


Rotation can occur around sigma bonds because they are formed when two orbitals overlap end-to-end.



Bonding in Ethene (sp^2)

Two sp^2 orbitals overlap to form a single sigma C-C bond. The unhybridized 2p orbitals at 90 degrees to this also overlap with each other to form a second bond called a pi bond. Ethene molecules have a **trigonal planar** shape with bond angles of **120°** . These molecules contain both sigma and pi bonds (see diagram).



The molecule is planar because there is **restricted rotation** around the C=C pi (π) bond. Rotation is restricted around this pi bond because the bond is formed when orbitals overlap below and above the plane of atoms.

Isomerism

Structural Isomers

Structural isomers are molecules with the **same molecular formula** but a different structural formula. There are different types of structural isomerism:

- **Chain** isomerism: This occurs when there is branching on the carbon chain.
- **Functional group** isomerism: The functional groups on the carbon chain changes.
- **Positional** isomerism: The carbon chain backbone remains the same but the groups attached to the chain move around and change position.

Structural isomerism	Isomer 1	Isomer 2
Chain	$CH_3CH_2CH_2CH_2CH_3$	$C(CH_3)_4$
Functional group	CH_3COCH_3 (ketone)	CH_3CH_2CHO (aldehyde)
Position	$CH_3CH=CHCH_3$	$CH_2=CHCH_2CH_3$

Stereoisomerism

Stereoisomers are molecules with the **same molecular and structural formula** but a different arrangement of **atoms in space**. **Geometrical (cis-trans) isomerism** and **optical isomerism** are both types of stereoisomerism.



Geometrical (cis-trans) Isomerism

Geometrical isomerism is a branch of stereoisomerism. It can also be called **cis-trans or E/Z isomerism**. This type of isomerism occurs due to a **pi bond** which **restricted rotation** around the C=C double bond. Since there is restricted rotation around this bond, the **various groups attached** to the carbon are **fixed in position** meaning different isomers can form. Examples of this type of isomerism are shown below (see example 1 in 'Isomerism in alkenes').

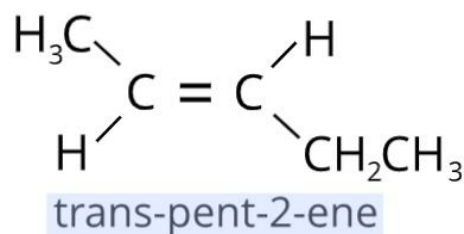
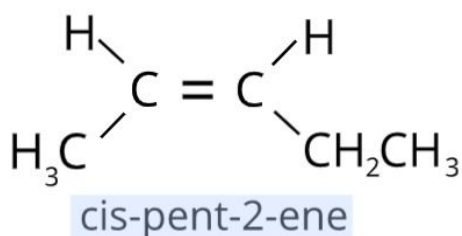
Isomerism in Alkenes

Geometrical isomerism is the type of isomerism that occurs in alkenes because it relies on a C=C double bond due to its restricted rotation. The **cis isomer** has **both of the highest priority groups on the same end** (either both above or below the C=C bond). The **trans isomer** the highest priority groups **diagonally across** from each other, on opposite sides of the double bond.

The priority of a group is decided by **atomic number**.

Example:

For the isomers below, the highest priority group on the left hand side is the methyl group, CH₃, and on the right hand side it is the ethyl group, CH₂CH₃.



Optical Isomerism

Optical isomerism is another branch of **stereoisomerism**. It occurs when there is a **chiral centre**, which is explained in more depth below. Optical isomers have the same molecular and structural formula but they are **mirror images** of one another since the atoms are arranged differently in space.

What is a Chiral Centre?

A chiral centre is an **atom with four different groups bonded** to it. This arrangement creates compounds which are **non-superimposable mirror images** of each other. If a compound has a chiral centre, it will display **optical isomerism**. It is possible for compounds to have **more than one chiral centre**.



Identifying Chiral Centres

Chiral centres can be identified in organic compounds by spotting a **carbon atom which is bonded to four different groups**.

Example:

The carbon highlighted in the compound below is a **chiral centre** since it is bonded to four different groups: a hydrogen atom, a methyl group, an alcohol group and an ethyl group.



This compound displays **optical isomerism**. The isomers can be drawn in a **tetrahedral** shape with the chiral carbon at the centre. It is easiest to draw these isomers by drawing one then **mirroring** it on the other side of the page:

