

Introduction to Organic Chemistry

A-Level Chemistry ■ Topic 13

A-Level Chemistry



What we will cover

- 1 Types of formula
- 2 Bond fission
- 3 Nucleophiles & electrophiles
- 4 Mechanisms
- 5 Hybridisation & shapes
- 6 Isomerism



the feedstock of organics



Types of formula

empirical

CH_2 – simplest ratio

molecular

C_2H_4 – actual numbers

structural

$\text{CH}_2=\text{CH}_2$ – how they join

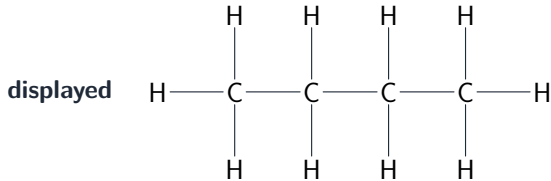
displayed

every bond drawn

Types of formula, in detail

molecular C_4H_{10}

structural $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_3$



skeletal



The same molecule (butane) shown four ways – molecular, structural, displayed and skeletal – each

The formula types, and the reaction types

empirical formula

the simplest whole-number ratio of atoms

molecular formula

the actual number of each atom in one molecule

displayed formula

every atom and every bond drawn out

hydrolysis

a molecule is **split apart by water**

condensation

two molecules join and a **small molecule such as water is lost**

organic redox

[O] stands for one oxygen atom from an oxidising agent, and
[H] for one hydrogen from a reducing agent

[O] and [H] are a shorthand that keeps organic equations balanced without writing out the whole oxidising agent. Use them – the mark scheme does.

Five ways to write the same compound

General formula

The pattern for a whole family: alkanes are C_nH_{2n+2} .

Molecular formula

The actual number of each atom: C_4H_{10} .

Structural formula

The groups in order: $CH_3CH_2CH_2CH_3$.

Displayed formula

Every atom and every bond drawn out – what a mechanism question needs.

Skeletal formula

Lines for bonds, carbons at the corners, hydrogens on carbon not shown.

A **homologous series** is a family sharing one functional group and one general formula, each member differing by CH_2 .

Naming

Use systematic **nomenclature** : a stem for the number of carbons (meth-, eth-, prop-, but-, pent-, hex- for 1 to 6), an ending for the functional group.

Bond fission

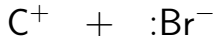
- **homolytic fission** – one electron each $\rightarrow$ two **free radicals**
- **heterolytic fission** – both electrons to one atom $\rightarrow$ two ions

homolytic fission



one electron each
 $\Rightarrow$ two **radicals**

heterolytic fission



both electrons to one
 $\Rightarrow$ two **ions**

Nucleophiles and electrophiles

nucleophile



a lone pair attacks
the electron-poor
($\delta+$) carbon

electrophile



it is drawn to the
electron-rich $\text{C}=\text{C}$
double bond

- a **nucleophile** (lone pair) attacks an electron-**poor** centre
- an **electrophile** is drawn to an electron-**rich** centre ($\text{C}=\text{C}$)

Reaction types: **addition** ,
substitution , **elimination** ,
hydrolysis .

Mechanisms

free-radical substitution –
alkanes

electrophilic addition – alkenes

nucleophilic substitution –
halogenoalkanes

nucleophilic addition – car-
bonyls

Free-radical steps: **initiation** → **propagation** → **termination** . A curly arrow shows a **pair** of electrons moving.

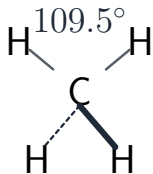


Hybridisation and shapes

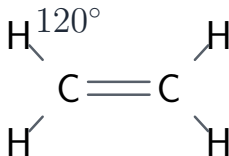
- sp^3 – tetrahedral, 109.5°
- sp^2 – planar, 120° (ethene)
- sp – linear, 180°

Single = σ ; double = $\sigma + \pi$.

Hybridisation and shapes, in detail



sp³: 4 single bonds
tetrahedral



sp²: 1 double + 2 single
planar (flat)



sp: 1 triple bond
linear

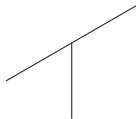
The shape at a carbon follows from its hybridisation: sp³ is tetrahedral (109.5°), sp² is planar (120°), sp is linear (180°)

Structural isomerism

chain

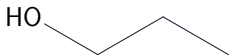


butane

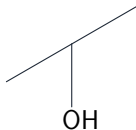


2-methylpropane

positional

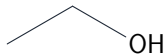


propan-1-ol

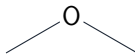


propan-2-ol

functional



ethanol (alcohol)

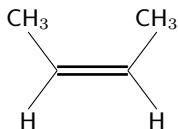


methoxymethane (ether)

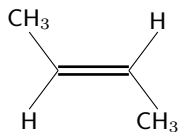
Same molecular formula, atoms joined differently:

- **chain**
- **positional**
- **functional group**

Stereoisomerism

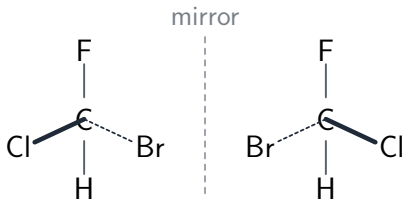


cis
both CH₃
same side

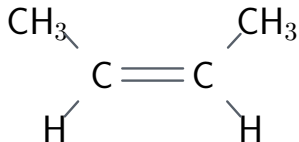


trans
CH₃
opposite sides

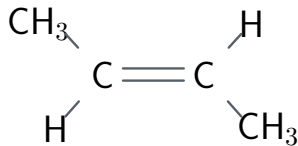
cis vs trans at C=C



Stereoisomerism, continued



cis: both CH₃ on
the same side



trans: CH₃ on
opposite sides

Cis-trans isomerism at a C=C bond: the methyl groups are fixed on the same side (cis) or opposite sides (trans) because the bond cannot rotate

Isomerism, and where stereoisomerism comes from

structural isomerism

the atoms are joined in a different order

chain, position, functional group

the three kinds – a different skeleton, a different position, or a different group entirely

stereoisomerism

the atoms are joined in the **same** order but **point in different directions** in space

cis-trans

restricted rotation about a C=C double bond, or around a ring (**cyclic**)

optical isomerism

a **chiral centre** : a carbon with **four different groups**

the test

a chiral molecule is non-superimposable on its mirror image, and rotates plane-polarised light

Look for the C=C or the four-different-groups carbon. Those two features are what *make* a molecule capable of stereoisomerism at all.

The kinds of isomerism

Chain isomerism

Structural: the carbon skeleton is branched differently.

Positional isomerism

Positional isomerism : the same functional group sits on a different carbon.

Functional group isomerism

Functional group isomerism : the same atoms form a *different* functional group – an alcohol and an ether.

Geometrical isomerism

Stereo: **geometrical isomerism** (cis/trans) at a C=C double bond, because the double bond cannot rotate.

Optical isomerism

Stereo: a carbon with four different groups gives two non-superimposable mirror images.

A **saturated** compound has only single C–C bonds; an **unsaturated** one has a double or triple bond – and that is exactly what makes geometrical isomerism possible.

Shapes of organic molecules



Organic molecules have definite three-dimensional shapes.

Exam tips

- Know the difference between **general, molecular, structural, displayed and skeletal** formulas – questions ask for a specific one.
- Name systematically: longest chain, lowest locants, substituents alphabetical; a wrong locant loses the mark.
- Classify each reaction by **type and reagent** (addition, substitution, elimination, oxidation).
- **E/Z isomerism** needs restricted rotation about a $C = C$ **and** two different groups on each carbon.



Worked example – structural isomers

Draw and name the structural isomers of C_4H_{10} , and state the type of isomerism.

- Straight chain: $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_3$ – **butane**.
- Branched: $(\text{CH}_3)_3\text{CH}$ – **2-methylpropane**.
- There are **only two**: a 3-carbon chain cannot take a CH_3 anywhere else.
- Same molecular formula, different skeleton $\Rightarrow$ **chain isomerism**.

Isomers share a **molecular** formula. **Chain** = different skeleton; **position** = group moved; **functional group** = a different group entirely.

Topic 13 – key takeaways

1

Functional group

the reactive part sets the properties

2

Bond fission

homolytic (radicals) vs heterolytic (ions)

3

Shapes

$sp^3/sp^2/sp$ give
tetrahedral/planar/linear

4

Isomerism

structural; cis/trans; optical (chiral)

Breaking bonds

- **homolytic fission** : the bond splits evenly, one electron to each atom. This makes two **free radicals** (species with an unpaired electron).
- **heterolytic fission** : the bond splits unevenly, both electrons going to one atom. This makes two ions.

Attacking species

- a **nucleophile** is a species with a lone pair that is attracted to a positive (electron-poor) centre.
- an **electrophile** is a species attracted to a negative (electron-rich) centre, such as a $\text{C}=\text{C}$ double bond.

Check yourself

- 1 Homolytic fission makes two of what?
- 2 A nucleophile attacks an electron-rich or electron-poor centre?
- 3 What is the shape at an sp^2 carbon?
- 4 A chiral carbon has how many different groups?



Answers 1. free radicals 2. electron-poor 3. planar (120°) 4. four