Isomerism

It is possible for organic molecules with the same molecular formula to have different structures

**Definition - Structural isomers:** same molecular formula different structures (or structural formulae)

There are three types of structural isomerism:
- Chain isomerism
- Position isomerism
- Functional group isomerism

**Chain isomerism:** Compounds with the same molecular formula but different structures of the carbon skeleton

These isomers arise because of the carbon chains can be branched. For example, there are two isomers of butane, $\text{C}_4\text{H}_{10}$. In one of them, the carbon atoms lie in a "straight chain" whereas in the other the chain is branched.

There are three isomers of pentane $\text{C}_5\text{H}_{12}$

False isomers

Do not draw "false" isomers which are just twisted versions of the original molecule. Twisting the molecule into a different shape does not make a different isomer. Isomers are only formed if a bond would have to be broken and reassembled into the different structure.

These are all exactly the same compound.
### Functional group isomers

Compounds with the same molecular formula but with atoms arranged to give different functional groups.

### Position isomers

Compounds with the same molecular formula but different structures due to different positions of the same functional group on the same carbon skeleton.

### Molecular Formula

<table>
<thead>
<tr>
<th>Molecular Formula</th>
<th>Number of possible isomers</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{C}<em>2\text{H}</em>{10}$</td>
<td>2</td>
</tr>
<tr>
<td>$\text{C}<em>3\text{H}</em>{12}$</td>
<td>3</td>
</tr>
<tr>
<td>$\text{C}<em>4\text{H}</em>{14}$</td>
<td>5</td>
</tr>
<tr>
<td>$\text{C}<em>5\text{H}</em>{16}$</td>
<td>9</td>
</tr>
<tr>
<td>$\text{C}<em>6\text{H}</em>{18}$</td>
<td>18</td>
</tr>
<tr>
<td>$\text{C}<em>7\text{H}</em>{20}$</td>
<td>35</td>
</tr>
<tr>
<td>$\text{C}<em>{10}\text{H}</em>{22}$</td>
<td>75</td>
</tr>
<tr>
<td>$\text{C}<em>{11}\text{H}</em>{24}$</td>
<td>4,347</td>
</tr>
<tr>
<td>$\text{C}<em>{12}\text{H}</em>{24}$</td>
<td>336,319</td>
</tr>
<tr>
<td>$\text{C}<em>{30}\text{H}</em>{62}$</td>
<td>4,111,846,763</td>
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### Number of Possible Chain Isomers for Selected Alkanes

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**Position isomers:** Compounds with the same molecular formula but different structures due to different positions of the same functional group on the same carbon skeleton.

**Functional group isomers:** Compounds with the same molecular formula but with atoms arranged to give different functional groups.

- Ethanol: an alcohol
- Methoxymethane: an ether
- Cyclohexane: cyclo alkane
- $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}=\text{CH}_2$: hexene: alkene

Aldehydes and ketones of the same chain length would be classed as functional group isomers - e.g. Propanal and propanone (both $\text{C}_3\text{H}_6\text{O}$)
**Structural Isomer Questions**

1) a) Define what a structural isomer is.
   b) Define what a molecular formula is.

2) Draw all the structural isomers of hexane and name them. What type of structural isomers are these isomers?

3) a) Draw the displayed formulae and name all the straight-chain isomers with the molecular formula C₄H₈Br₂
   b) Name the type of structural isomerism that these isomers show and explain why

4) a) Name and draw the displayed and skeletal formulae of a functional group isomer of pent-1-ene
   b) Name and draw the displayed and skeletal formulae of a positional isomer of pent-1-ene
   c) Name and draw the displayed and skeletal formulae of a chain isomer of pent-1-ene

5) The following is the structure of methoxyethane

   \[
   \begin{align*}
   &\text{H} &\text{H} &\text{H} \\
   &\text{H} &\text{C} &\text{C} &\text{O} &\text{C} &\text{H} \\
   &\text{H} &\text{H} &\text{H} &\text{H}
   \end{align*}
   \]

   a) Draw the displayed formulae and name a functional group isomer of methoxyethane
   b) Draw the displayed formulae and name a positional isomer of the compound you have drawn in part 5a

6) Draw the skeletal formulas of the structural isomers of the different alcohols with the molecular formula C₄H₁₀O. Name the isomers.

7) Deduce the number of structural isomers for Hexane C₆H₁₄

8) Name the compound on the right and draw its skeletal formula. Deduce how many other position isomers of the compound on the right can be formed.

9) Compound Y is shown below. It is a member of a homologous series of hydrocarbons.

   \[
   \begin{align*}
   &\text{H} &\text{C} &\text{C} &\text{C} &\text{C} &\text{H} \\
   &\text{H} &\text{H} &\text{H} &\text{H} &\text{H} &\text{H}
   \end{align*}
   \]

   (a) Write the general formula of the homologous series that contains Y.
   (b) Name a process used to obtain a sample of Y from a mixture containing other members of the same homologous series.
   (c) Name and draw the skeletal formula of a position isomer of Y.
   (d) Name and draw the skeletal formula of a functional group isomer of Y.
**Stereoisomerism**

**Definition:** Stereoisomers have the same structural formulae but have a different spatial arrangement of atoms.

There are two types of stereoisomerism: geometrical (E-Z isomerism) and optical isomerism.

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### E-Z stereoisomerism

Alkenes can exhibit a type of isomerism called **E-Z stereoisomerism**. This occurs because of restricted rotation that occurs around a double bond.

**C=C double bonds have restricted rotation**, due to position of the pi bond, so the groups on either end of the bond are fixed in one position. It is not easy to flip between the two.

This produces two possibilities. The two structures cannot interchange easily so the atoms in the two molecules occupy different positions in space.

**E-Z stereoisomers arise when:**
- There is **restricted rotation** around the C=C double bond.
- There are **two different groups/atoms** attached both ends of the restricted double bond.

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**Same structure NOT E-Z stereoisomers:** two identical groups attached to one end of the restricted double bond.
Naming E-Z stereoisomers

Cahn–Ingold–Prelog (CIP) priority rules.

On both sides of the double bond determine the priority group

1. Compare the atomic number ($A_r$) of the atoms directly attached to each side of the double bond; the group having the atom of higher atomic number receives higher priority.

2. If there are groups of atoms instead of single atoms attached to the carbon of the double bond then consider the sum of the atomic numbers of the entire group. The bigger group is the priority.
cis-trans isomerism

In some text books you will find this type of E-Z isomerism referred to as geometric isomerism and cis-trans isomerism. cis-trans isomerism can be considered as a special case of E/Z isomerism in which two of the substituent groups are the same. It has been superseded by E/Z isomerism because the Cahn–Ingold–Prelog (CIP) priority rules allow all alkenes to be considered and not just the ones where the groups are the same.

\[
\begin{align*}
Z\text{-but-2-ene} \\
\text{Can also be called} \\
\text{Cis- but-2-ene}
\end{align*}
\]

Cis means “on this side of” in Latin

\[
\begin{align*}
E\text{-but-2-ene} \\
\text{Can also be called} \\
\text{trans- but-2-ene}
\end{align*}
\]

trans means “across” in Latin

The effect of E/Z stereoisomerism on physical properties

E-Z stereoisomers can have differing melting and boiling points.

\[
\begin{align*}
\text{Z-1,2-dichloroethene} \\
\text{Boiling point =60°C} \\
\text{This molecule is polar. The polar C-Cl bonds are on the same side of the molecule. One side of the molecule is slightly negative.} \\
\text{The intermolecular forces are both London forces and permanent dipole-dipole attractions.}
\end{align*}
\]

\[
\begin{align*}
\text{E-1,2-dichloroethene} \\
\text{Boiling point =48°C} \\
\text{This molecule is non-polar. The polar C-Cl bonds are on opposite sides of the molecule.} \\
\text{The dipoles cancel out.} \\
\text{The intermolecular forces are is only London forces so lower boiling point.}
\end{align*}
\]
E-Z Isomerism Questions

1. State the meaning of the term stereoisomers.
2. Identify the feature of the double bond in but-2-ene that causes it to form two E-Z stereoisomers.
3. Draw structural formulae of the E-Z isomers of the following compounds:
   a) 3-methylpent-2-ene.
   b) but-2-ene
   c) 3-methylpent-2-ene
   d) pent-3-en-2-ol
   e) hex-3-ene
   f) pent-2-ene
4. Name the following including the correct E-Z letter at the start of the name:

5. Compound A has the molecular formula C_{5}H_{10}O. It has a branched carbon chain and exists as a pair of E-Z Stereoisomers. Draw the structures and name the two Isomers.

6. Using the carbon skeleton like it is drawn on the right, Draw the 3 stereoisomers of 1,4-dichlorobuta-1,3-diene.

7. Draw the two E-Z stereoisomers of hex-4-en-2-one.

8. Explain why the following weak unsaturated acid CH_{3}(CH)_{4}COOH shows E-Z isomerism. Draw the structures of each of the E-Z isomers of this acid.

9. How many E-Z stereoisomers are there of the molecule shown below, including the molecule shown?
Optical Isomerism

Optical isomerism occurs in carbon compounds with 4 different groups of atoms attached to a carbon (called an asymmetric carbon).

A carbon atom that has four different groups attached is called a chiral (asymmetric) carbon atom.

This causes two different isomers that are not superimposable to be formed. They are mirror images.

If the compound does not have 4 different groups then when it is rotated it will be superimposable.

Butan-2-ol has four different groups around a carbon and so forms optical isomers.

Two compounds that are optical isomers of each other are called enantiomers.
Optical isomers have similar physical and chemical properties, but they rotate plane polarised light in different directions.

One enantiomer rotates it in one direction and the other enantiomer rotates it by the same amount in the opposite direction.

One optical isomer will rotate light clockwise (++) (called dextrorotatory). The other will rotate it anticlockwise (--) (called laevorotatory).

### Polarimeter

The rotation of light by a chiral compound can be observed by using a polarimeter. The light source will produce unpolarised light which is light travelling in all planes. If this light is passed through a polarising filter then plane polarised light will be formed, which is light that only travels in one plane. When this passes through the sample of the chiral substance the plane polarised light will rotated in to a different plane.

**Method for using a polarimeter**

• first put water in sample tube and rotate analysing filter to block out light
• replace water with sample. If the sample is chiral light will be seen
• rotate analysing filter again to block out light. The amount the analyser is rotated is the amount the light has been rotated.
R/S Nomenclature

Different systems of nomenclature are in existence for optical isomers. D/L or +/- are commonly used, but both have been superseded by the more informative R/S system.

1) Using the Cahn–Ingold–Prelog (CIP) priority rules, used in EZ isomerism, assign a priority number for each of the four groups. The ones with the highest atomic number have the higher priority.

2) Redraw the molecule with the atom with the lowest priority pointing into the plane of the page (in this case H).

3) Imagine moving from substituent 1 to 2 to 3. If moving in a clockwise direction then assign the compound the R letter. If moving anticlockwise the assign the compound the S letter.

This is an S enantiomer.
Racemic mixtures

A mixture containing a 50/50 mixture of the two isomers (enantiomers) is described as being a **racemate** or **racemic mixture**.

A racemic mixture (a mixture of equal amounts of the two optical isomers) **will not rotate** plane-polarised light.

**Chemical Reactions and Optical Isomers**

**Formation of a racemate**

A racemate will be formed in a reaction mechanism when a trigonal planar reactant or intermediate is approached from both sides by an attacking species.

A racemate can also be formed in the reaction of the electrophilic addition of HBr to an unsymmetrical alkene.

Nucleophilic addition of HCN to aldehydes and ketones (unsymmetrical) when the trigonal planar carbonyl is approached from both sides by the HCN attacking species: results in the formation of a racemate.

If the alkene is unsymmetrical, addition of hydrogen bromide can lead to isomeric products.
Nucleophilic substitution reactions and optical activity

In the topic of reactions of halogenoalkanes we look at the nucleophilic substitution reactions of halogenoalkanes with aqueous hydroxide ions to form alcohols. The reaction can occur via two different mechanisms called SN1 and SN2. Primary halogenoalkanes tend to undergo the SN2 mechanism and tertiary halogenoalkanes undergo the SN1 mechanism. Secondary halogenoalkanes can undergo either mechanism. The two different mechanisms have a different effect on optical activity of chiral reactants. By observing the differing effects it can give us evidence for which mechanism is occurring.

Nucleophilic substitution mechanism, SN1

The Br breaks off leaving a planar carbocation intermediate

The OH\(^{-}\) ion can then attack from either side resulting in different enantiomers and a racemate forms

Nucleophilic substitution mechanism, SN2

In the SN\(_2\) mechanism no intermediates are formed and the reaction occurs via a transition state

If the reactant was chiral then during the reaction the opposite enantiomer would form through inversion as shown below.
Drug action and optical isomers
Drug action may be determined by the stereochemistry of the molecule.
Different optical isomers may have very different effects.

Ibuprofen

Chiral carbon

Thalidomide

R thalidomide (dangerous drug)
S thalidomide (effective drug)

One enantiomer of thalidomide causes birth defects in unborn children whilst the other had useful sedative problems. It was used as a drug for treat pregnant women with morning sickness. At the time the side effect was not know. Unfortunately it was given in a racemic mixture when first used and many babies were born with birth defects.