Organic chemistry

IGCSE Chemistry

Organic chemistry is the chemistry of carbon compounds. Carbon is special because it can join to other carbon atoms to make long chains and rings.

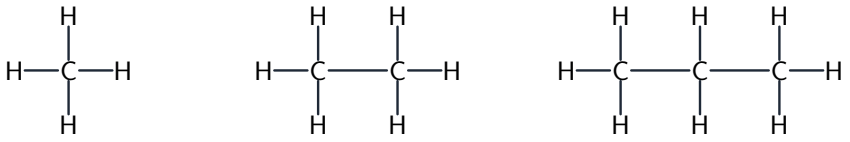
Formulae and key words

There are several ways to write an organic molecule:

- The **molecular formula** 分子式 shows how many of each atom there are, for example C_2H_6.
- The **displayed formula** 结构式 shows every atom and every bond drawn out in full.
- The **structural formula** 结构简式 shows how the atoms are arranged without drawing every bond, for example CH_3CH_2OH.
- The **general formula** 通式 works for a whole family, for example C_nH_{2n+2} for alkanes.

A **homologous series** 同系物 is a family of compounds with the same **functional group** 官能团—the atom or group of atoms that gives the family its chemical properties. Members of a series have the same general formula, differ by a CH_2 unit each step, and have similar chemical properties with a gradual change in physical properties.

Series	Functional group	General formula
alkanes	C–C single bonds only	C_nH_{2n+2}
alkenes	C=C double bond	C_nH_{2n}
alcohols	–OH	$C_nH_{2n+1}OH$
carboxylic acids	–COOH	$C_nH_{2n+1}COOH$

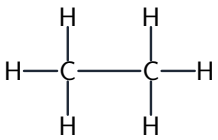


methane CH_4 | ethane C_2H_6 | propane C_3H_8

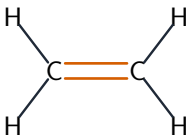
each step adds a CH_2 unit | general formula C_nH_{2n+2}

The alkanes are a homologous series: each member has one more CH_2 unit (general formula C_nH_{2n+2})

A **saturated** 饱和 compound has only single carbon–carbon bonds. An **unsaturated** 不饱和 compound has one or more carbon–carbon bonds that are not single (such as a C=C double bond).



ethane C_2H_6
saturated: single C–C bond

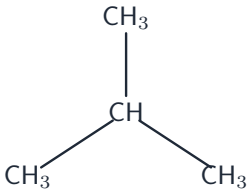


ethene C_2H_4
unsaturated: C=C double bond

A saturated compound has only single C–C bonds; an unsaturated one has a C=C double bond

Structural isomers 同分异构体 are compounds with the same molecular formula but different structural formulae. For example, C_4H_{10} can be a straight chain or a branched chain.

butane (straight chain)



2-methylpropane (branched)

both have the formula C_4H_{10}: same formula, different structure (structural isomers)

Structural isomers: butane and 2-methylpropane share the formula C_4H_{10} but have different structures

Naming organic compounds

The end of the name tells you the family:

Ending	Family	Example
-ane	alkane	methane, ethane
-ene	alkene	ethene
-ol	alcohol	ethanol
-oic acid	carboxylic acid	ethanoic acid

The start of the name tells you the number of carbon atoms: *meth-* = 1, *eth-* = 2, *prop-* = 3, *but-* = 4. For longer alkenes and alcohols, a number shows where the functional group is, for example but-1-ene and but-2-ene, or propan-1-ol and propan-2-ol.

Fuels

An oil refinery separates crude oil into useful fuels by fractional distillation.

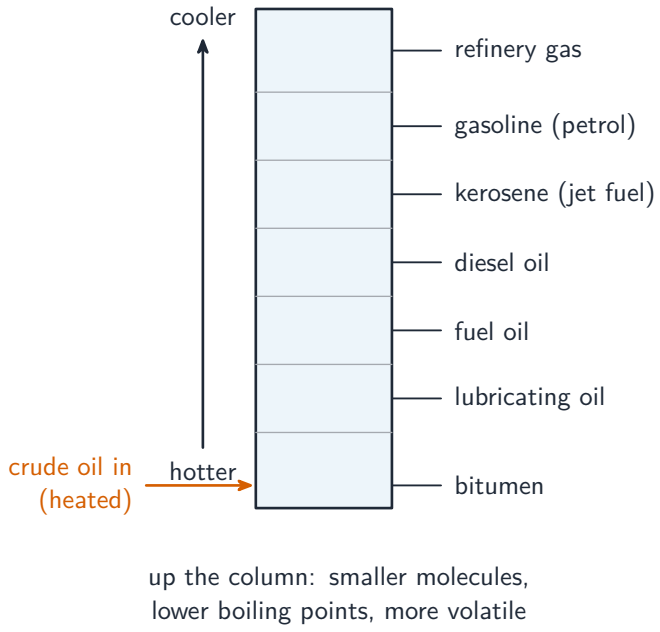
The three **fossil fuels** 化石燃料 are **coal** 煤, **natural gas** 天然气 and **petroleum** 石油 (crude oil). **Methane** 甲烷 is the main part of natural gas.

A **hydrocarbon** 碳氢化合物 is a compound made of hydrogen and carbon only. Petroleum is a mixture of many different hydrocarbons.

Fractional distillation

Petroleum is separated into useful **fractions** 馏分 by **fractional distillation** 分馏. The mixture is heated, and the different hydrocarbons turn to gas and rise up a tall **fractionating column** 分馏塔. The column is hot at the bottom and cool at the top, so each fraction turns back to liquid at a different height.

At an oil refinery, crude oil is separated in the tall fractionating columns you can see rising above the plant



Fractions separate by boiling point: small molecules leave the cool top, thick bitumen stays at the hot bottom

Going from the bottom to the top of the column, the fractions have:

- shorter **chain length** 链长 (smaller molecules);
- higher **volatility** 挥发性 (they turn to gas more easily);
- lower boiling points;
- lower **viscosity** 黏度 (they flow more easily).

Fraction	Use
refinery gas	gas for heating and cooking
gasoline / petrol	fuel for cars
naphtha	raw material for making chemicals
kerosene / paraffin	jet fuel
diesel oil	fuel for diesel engines
fuel oil	fuel for ships and home heating
lubricating oil	lubricants, waxes and polishes
bitumen 沥青	making roads

Alkanes

Alkanes 烷烃 have only single covalent bonds, so they are saturated hydrocarbons. They are generally unreactive. Their two important reactions are:

- **Combustion** 燃烧: they burn in plenty of oxygen to give carbon dioxide and water.
- **Substitution** with chlorine.

In a **substitution reaction** 取代反应, one atom (or group of atoms) is replaced by another. Alkanes react with chlorine only in **ultraviolet light** 紫外线—this is a **photochemical reaction** 光化学反应, where the light provides the **activation energy** 活化能. For example:

$$CH_4 + Cl_2 \rightarrow CH_3Cl + HCl$$

Alkenes

Alkenes 烯烃 have a carbon–carbon double bond (C=C), so they are unsaturated hydrocarbons.

Cracking

Large alkane molecules are not very useful. **Cracking** 裂化 breaks them into smaller, more useful molecules —smaller alkanes and alkenes —using a high temperature and a **catalyst** 催化剂. Cracking also makes **hydrogen** 氢气 and provides alkenes for making plastics.

Reactions of alkenes

The C=C double bond makes alkenes reactive. They take part in **addition reactions** 加成反应, where two molecules join to form a single product.

- **Test for unsaturation**: shake the compound with **bromine** 溴 water (which is orange). An alkene turns the bromine water colourless; an alkane does not change it.
- With hydrogen and a **nickel** 镍 catalyst, an alkene becomes an alkane.
- With **steam** 蒸汽 and an acid catalyst, an alkene becomes an alcohol.

Alcohols

Alcohols 醇 contain the –OH functional group. The most important one is **ethanol** 乙醇. There are two ways to make ethanol.

Method	Conditions	Notes
fermentation 发酵 of glucose	yeast, 25–35 °C, no oxygen	uses renewable sugar, but slow and gives impure ethanol
addition of steam to **ethene** 乙烯	300 °C, 60 atm, acid catalyst	fast and pure, but uses petroleum (non-renewable)

In **fermentation**, **yeast** 酵母 turns **glucose** 葡萄糖 into ethanol and carbon dioxide.

Ethanol burns well (combustion), so it is used as a **fuel**. It also dissolves many substances, so it is used as a **solvent** 溶剂.

Carboxylic acids

Carboxylic acids 羧酸 contain the –COOH functional group. **Ethanoic acid** 乙酸 is the one to know. Like other acids, it reacts with:

- **metals** 金属 → a salt + hydrogen;
- **bases** 碱 → a **salt** 盐 + water;
- **carbonates** 碳酸盐 → a salt + water + carbon dioxide.

The salts formed are called ethanoates.

Ethanoic acid can be made by the **oxidation** 氧化 of ethanol, either using acidified **potassium manganate(VII)** 高锰酸钾, or by bacteria during the making of **vinegar** 醋.

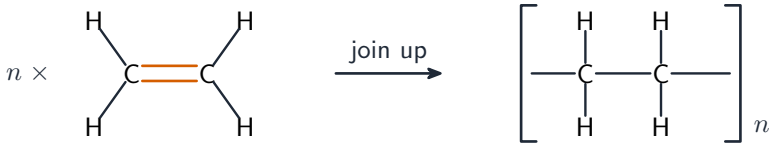
When a carboxylic acid reacts with an alcohol (using an acid catalyst), it forms an **ester** 酯.

Polymers

A **polymer** 聚合物 is a very large molecule built from many small molecules called **monomers** 单体.

Addition polymerisation

In **addition polymerisation** 加聚, many unsaturated monomers join together with no other product. For example, many ethene monomers join to make poly(ethene). The small part that repeats along the chain is the **repeat unit** 重复单元.



ethene (monomer) poly(ethene) repeat unit

In addition polymerisation the C=C bonds open up and many ethene monomers join into a long poly(ethene) chain

Condensation polymerisation

In **condensation polymerisation** 缩聚, monomers join and a small molecule (usually water) is lost each time a bond forms. This makes two important types:

- **Polyamides** 聚酰胺 are made from a dicarboxylic acid and a diamine. **Nylon** 尼龙 is a polyamide.
- **Polyesters** 聚酯 are made from a dicarboxylic acid and a diol. PET is a polyester, and it can be broken back into its monomers and re-made.

Plastics and the environment

Plastics 塑料 are made from polymers. Because many plastics do not break down, getting rid of them is a problem:

- they build up in **landfill** 填埋 sites;
- they collect in the oceans and harm sea life;
- burning them can make toxic gases.

Proteins

Proteins 蛋白质 are natural polyamides. They are made from **amino acid** 氨基酸 monomers joined in long chains.