

Step 5 Discovering organic chemistry

Here is a review of the main concepts of this step!

1 Organic compounds

Organic chemistry studies structure, properties, composition, and reactions of organic compounds. All organic compounds contain carbon, but not all carbon compounds are classified as organic.

These elements typically include elements like oxygen, nitrogen, sulphur, phosphorus, or halogens. The unique bonding properties of carbon lead to a vast number of organic compounds.

Historically, chemists believed organic compounds were exclusive to living organisms until 1828, when Friedrich Wöhler synthesized urea and demonstrated that compounds in living organisms could be replicated from non-living sources. This discovery shifted the definition of organic chemistry to focus on carbon-containing compounds. Wöhler's work established that organic compounds are not unique to living organisms, paving the way for the synthesis of hundreds of organic compounds.

2 The key role of carbon

Carbon is one of the most abundant elements on the Earth and is essential for all known life forms. It is also the second most abundant element by mass in the human body after oxygen. Its ability to form a diverse range of organic compounds and polymers explains the chemistry of life. Carbon can form four covalent bonds, making it possible to create long, complex chains and three-dimensional structures. These chains can be theoretically limitless in length, with some large hydrocarbon molecules containing up to 100,000 carbon atoms.

Carbon atoms can bond with each other and with various elements such as hydrogen, oxygen, and nitrogen, forming strong single, double, or triple bonds. This versatility and bonding capability make carbon uniquely suited to form the backbone of life's molecular structures. Carbon chains can take different forms: backbone, branches or rings.

The variety of carbon chain forms contributes significantly to isomerism in carbon compounds. Isomerism refers to the existence of molecules with the same number and types of atoms but different structures or spatial arrangements. Isomers share the same molecular formula but differ in chemical and physical properties due to these structural differences.

3 **Types of organic compounds: polymers**

Polymers, which include both natural and synthetic substances, are composed of large molecules made of repeating units called monomers. They are essential in living organisms for structure and function, seen in materials like cellulose, proteins, and DNA. Synthetic polymers, such as nylon, have a wide range of uses in modern society.

Polymerization

Polymerization is the process by which monomers chemically bond to form large, high-molecular-weight compounds.

Polymer morphology

Polymer morphology, which includes features like crystallinity and branching, determines the physical properties of polymers. Polymers can be semicrystalline, combining strong but brittle crystalline regions with tough, flexible amorphous regions. This structural diversity allows polymers to have varied properties like elasticity and high tensile strength.

4 **Creating polymers**

Polymerization, the process of forming polymers, involves two types: condensation and addition.

Condensation and addition polymerization

- **Condensation polymerization** forms polymers while releasing small molecules like water.

- **Addition polymerization** forms polymers without byproducts, often using catalysts to control properties.

Linear and cross-linked polymers

- **Linear polymers** are chain-like, thermoplastic, melt with heat, and can be liquids or solids.
- **Cross-linked polymers** have a network structure, they are thermosetting, do not dissolve, and retain shape permanently after heating.

5 Classifying organic compounds

Organic compounds consist of carbon bonded with elements like hydrogen, nitrogen, oxygen, halogens, phosphorus, silicon, and sulphur through covalent bonds. This contrasts with inorganic compounds, which typically involve ionic bonds.

Bond types and diversity

Organic compounds feature single, double, or triple bonds and are continually expanding with new discoveries, adding to the over twenty million known compounds. This complexity necessitates classification into sub-groups or families.

Functional groups

Functional groups are specific arrangements of atoms that define a compound's chemical properties. Examples include hydroxyl (OH) in alcohols, carboxyl (COOH) in carboxylic acids, carbonyl (CO) in aldehydes, ketones, and quinones, and nitro (NO₂) in certain organic nitrogen compounds.

Organic families

Organic compounds are categorized based on their functional groups. Compounds sharing the same functional group belong to an organic family and exhibit similar characteristics. For example, alcohols, characterized by the hydroxyl group (OH), share properties such as solubility in water due to interactions between their hydroxyl groups and water molecules.

6 Discovering hydrocarbons and their derivatives

Hydrocarbons, the simplest organic compounds, consist solely of carbon and hydrogen. They vary widely in molecular structure and phase, appearing as gases, liquids, low melting solids, or polymers, and are typically colourless and hydrophobic.

Saturated and unsaturated hydrocarbons

- **Saturated hydrocarbons** are carbon and hydrogen atoms joined by single bonds. Alkanes are examples, such as methane, ethane, and propane. They exist as gases (e.g., methane), liquids (e.g., pentane), or solids (e.g., octane) and are flammable.
- **Unsaturated hydrocarbons** are carbon and hydrogen atoms joined by double or triple bonds.
- **Alkenes** have double bonds between carbon atoms (e.g., ethene, propene).
- **Alkynes** have triple bonds (e.g., ethyne or acetylene). They are highly reactive and mainly used industrially.

Hydrocarbon derivatives

Hydrocarbon derivatives form when functional groups substitute hydrocarbons. Examples include:

- Aromatic compounds
- Alcohols
- Ethers
- Aldehydes
- Ketones
- Carboxylic acids
- Esters
- Amines
- Amino acids
- Carbohydrates

These derivatives exhibit diverse chemical properties and are crucial in various industrial and biological processes.

7 Hydrocarbon exploitation: fossil fuels

Hydrocarbons, primarily found in fossil fuels like petroleum and natural gas, form deep within the Earth through natural processes. Due to their ease of combustion, fossil fuels have long served as crucial energy sources in industry and transportation, despite concerns over their environmental impact.

Environmental impact

- **Pollution:** Overuse of fossil fuels leads to significant carbon dioxide (CO₂) emissions, contributing to air pollution and climate change.
- **Health effects:** Direct combustion releases particulates that harm respiratory health, causing issues like coughing, lung inflammation, and potentially cancer.
- **Acid rain:** Combustion of crude oil and coal produces sulphur dioxide (SO₂) and nitrogen dioxide (NO₂), which can lead to acid rain when combined with oxygen in the atmosphere. This phenomenon can damage ecosystems and infrastructure.

Mitigation efforts

The Clean Coal Technology (CCT) is a refining process that reduces emissions of sulphur dioxide and nitrogen dioxide from coal combustion, improving efficiency and reducing pollution.

Despite efforts like CCT and stricter regulations, the reliance on fossil fuels poses ongoing challenges due to their environmental impact and finite availability.