FSc / ICS Part-II Chemistry — Punjab Board

CHAPTER 7

Fundamental Principles of Organic Chemistry

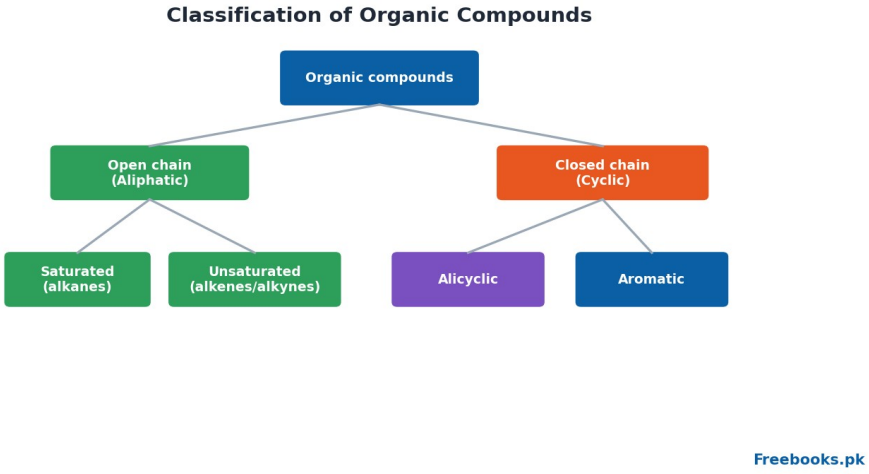

Figure 7.1 — Classification of organic compounds.

1. Chapter Overview

Organic chemistry is the chemistry of carbon compounds (chiefly hydrocarbons and their derivatives). Carbon is unique because it can bond to itself in long chains and rings (catenation) and form single, double and triple bonds, which is why there are millions of organic compounds — far more than all the compounds of the other elements together. This chapter lays the foundation for the whole organic section: where organic compounds come from, how they are classified, what functional groups and homologous series are, how carbon bonds (hybridization), and the main types of organic reaction.

2. Learning Objectives

- Define organic chemistry and explain the special nature of carbon.
- State the main sources of organic compounds.
- Classify organic compounds into aliphatic, alicyclic and aromatic types.
- Define functional group and homologous series with examples.
- Explain sp^3, sp^2 and sp hybridization of carbon.
- Explain structural isomerism.
- Identify the main types of organic reactions (addition, substitution, elimination).

3. Key Concepts

3.1 Why Carbon Is Special

Carbon has four valence electrons, so it forms four covalent bonds. It shows catenation (the ability to link with other carbon atoms to form chains and rings) to a greater extent than any other element, and it can form multiple bonds (C=C, C≡C). Because carbon–carbon bonds are strong, the resulting molecules are stable. Together these properties allow an almost unlimited variety of compounds.

3.2 Sources of Organic Compounds

The main natural sources of organic compounds are the fossil fuels — coal, petroleum (crude oil) and natural gas — together with plants and animals. Petroleum, separated by fractional distillation, provides fuels (petrol, diesel, kerosene) and the raw materials (from cracking) for plastics, medicines and countless other products.

3.3 Classification of Organic Compounds

Organic compounds are broadly divided into open-chain (aliphatic) compounds and closed-chain (cyclic) compounds. Cyclic compounds are further divided into alicyclic (ring compounds that behave like aliphatic ones) and aromatic compounds (those containing the benzene ring). Aliphatic compounds may be saturated (only single bonds, e.g. alkanes) or unsaturated (containing double or triple bonds, e.g. alkenes and alkynes).

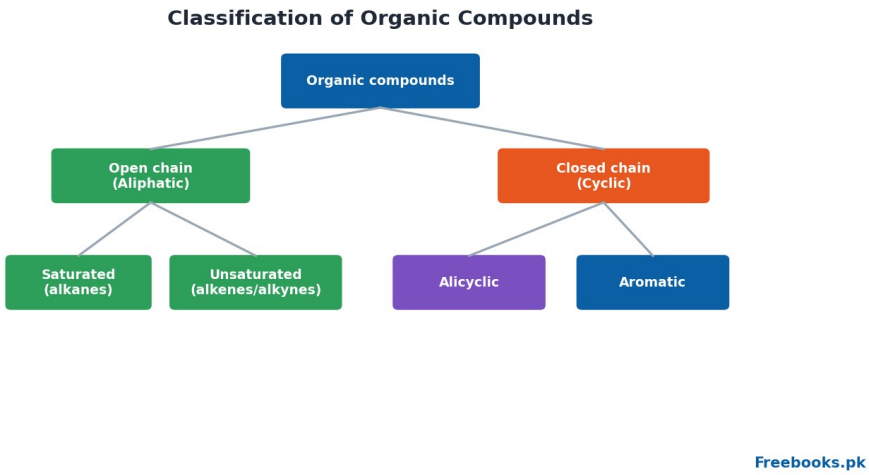

Figure 7.2 — Classification tree of organic compounds.

3.4 Functional Groups and Homologous Series

A functional group is the atom or group of atoms that gives a molecule its characteristic chemical properties; for example the –OH group makes a compound an alcohol. A homologous series is a family of organic compounds with the same functional group and general formula, in which each member differs from the next by a $–CH_2–$ unit. Members of a homologous series have similar chemical properties and show a gradual change in physical properties (such as boiling point) as the chain grows.

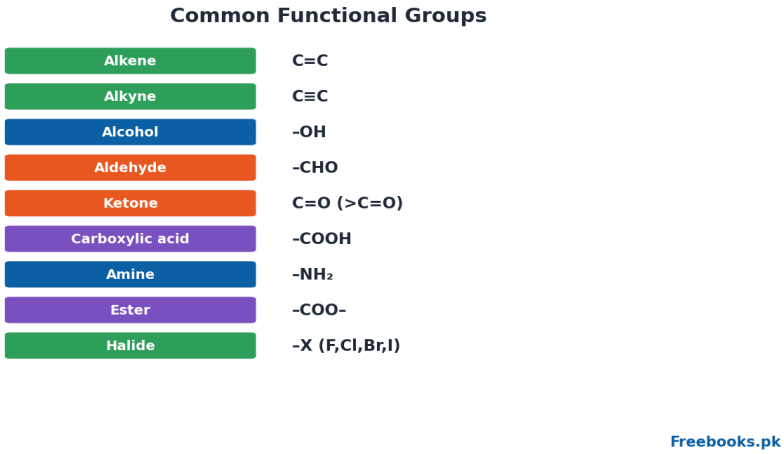

Figure 7.3 — Some common functional groups.

> **Memory Trick**
> **Alkane → alkene → alkyne** = single → double → triple bond ('-ane, -ene, -yne').
> **General formulas:** alkane C_nH_{2n+2}, alkene C_nH_{2n}, alkyne C_nH_{2n-2}.

3.5 Hybridization of Carbon

The shape and bonding of carbon are explained by hybridization — the mixing of atomic orbitals to give equivalent hybrid orbitals. In sp^3 hybridization (as in methane) carbon forms four single bonds arranged tetrahedrally at 109.5°. In sp^2 hybridization (as in ethene) carbon forms three σ-

bonds in a plane at 120°, plus one π-bond (a double bond). In sp hybridization (as in ethyne) carbon forms two σ-bonds at 180°, plus two π-bonds (a triple bond).

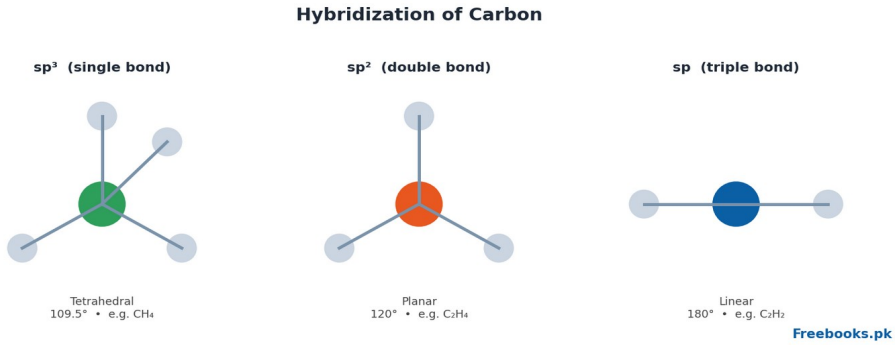

Figure 7.4 — sp³, sp² and sp hybridization of carbon.

Hybridization	Bond type	Shape / angle	Example
sp^3	4 single bonds	Tetrahedral, 109.5°	CH_4 (methane)
sp^2	1 double bond	Planar, 120°	C_2H_4 (ethene)
sp	1 triple bond	Linear, 180°	C_2H_2 (ethyne)

3.6 Isomerism

Isomers are compounds that have the same molecular formula but different structures. In structural isomerism the atoms are joined in a different order — for example, C_4H_{10} exists as n-butane (a straight chain) and isobutane (a branched chain). Isomerism is another reason organic compounds are so numerous.

3.7 Types of Organic Reactions

Addition. Atoms are added across a double or triple bond, e.g. ethene + H_2 → ethane. Typical of unsaturated compounds.

Substitution. One atom or group is replaced by another, e.g. methane + Cl_2 → chloromethane + HCl. Typical of saturated compounds.

Elimination. A small molecule (such as water or HX) is removed to create a double bond, e.g. dehydration of an alcohol to an alkene.

4. Important Definitions

Term	Definition
Organic chemistry	The study of carbon compounds, mainly hydrocarbons and their derivatives.
Catenation	The self-linking of carbon atoms into chains and rings.
Functional group	The atom or group that gives an organic molecule its characteristic properties.
Homologous series	A family of compounds with the same functional group and general

Term	Definition
	formula, differing by –CH_2–.
Hybridization	The mixing of atomic orbitals to form equivalent hybrid orbitals.
Isomers	Compounds with the same molecular formula but different structures.

5. Formulas / Rules

Must-Know Facts

General formulas: alkane C_nH_{2n+2}, alkene C_nH_{2n}, alkyne C_nH_{2n-2}.

Hybridization: sp^3 (109.5°, single), sp^2 (120°, double), sp (180°, triple).

Reaction types: addition (unsaturated), substitution (saturated), elimination (forms double bond).

Homologues differ by one –CH_2– unit and share chemical properties.

6. Diagrams / Illustrations

Key diagrams for revision:

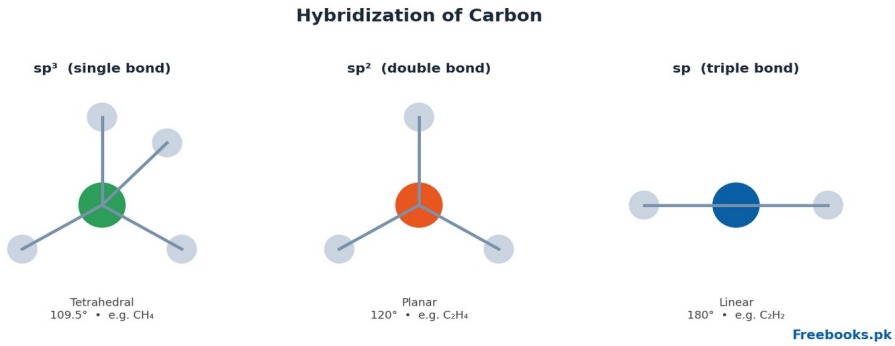

Diagram 1 — Hybridization of carbon.

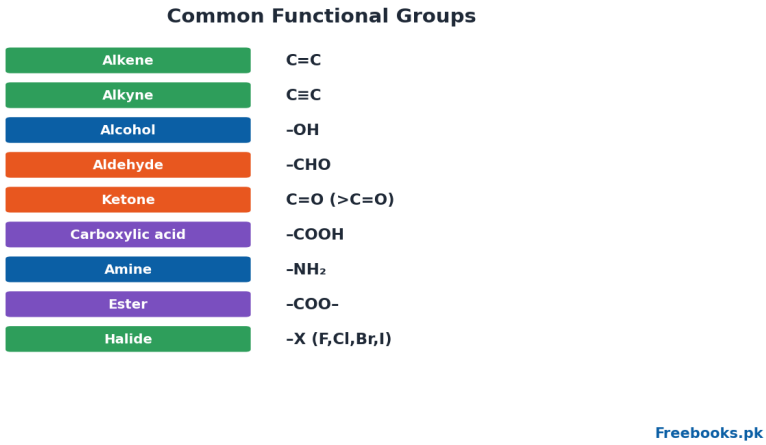

Diagram 2 — Common functional groups.

7. Solved Examples

Example 1 — Hybridization

Q: State the hybridization of carbon in ethyne (C_2H_2).

Solution: Each carbon in ethyne is sp hybridized. It forms two σ-bonds (linear, 180°) and the triple bond includes two π-bonds.

Example 2 — Isomerism

Q: Draw/describe the structural isomers of C_4H_{10}.

Solution: There are two: n-butane ($CH_3–CH_2–CH_2–CH_3$, straight chain) and isobutane/2-methylpropane (a branched chain). Same formula, different structure.

Example 3 — Reaction type

Q: Classify the reaction $CH_4 + Cl_2 \rightarrow CH_3Cl + HCl$.

Solution: It is a substitution reaction — a hydrogen atom of methane is replaced by a chlorine atom.

8. Short Questions

Q1. Why does carbon form so many compounds?
Ans. Because of catenation (self-linking into chains/rings) and its ability to form single, double and triple bonds.

Q2. Define functional group.
Ans. The atom or group of atoms that gives an organic compound its characteristic chemical properties.

Q3. What is a homologous series?
Ans. A family of compounds with the same functional group and general formula, each differing by a $–CH_2–$ unit.

Q4. Give the hybridization and shape of carbon in methane.
Ans. sp^3 hybridized, tetrahedral, bond angle 109.5°.

Q5. What are structural isomers?
Ans. Compounds with the same molecular formula but a different arrangement of atoms.

Q6. Differentiate addition and substitution reactions.
Ans. In addition, atoms add across a multiple bond; in substitution, one atom/group replaces another.

Q7. Name the main sources of organic compounds.
Ans. Coal, petroleum and natural gas (fossil fuels), and plants and animals.

Q8. Give the general formula of alkenes.
Ans. C_nH_{2n}.

9. Long Questions

Q1. Explain the classification of organic compounds.

Organic compounds are first divided, according to the shape of their carbon skeleton, into open-chain (aliphatic) and closed-chain (cyclic) compounds. Open-chain compounds have carbon atoms joined in straight or branched chains; they may be saturated, containing only single bonds (the alkanes), or unsaturated, containing double or triple bonds (the alkenes and alkynes). Closed-chain (cyclic) compounds have their carbon atoms joined in a ring, and they are further divided into alicyclic compounds, whose rings behave chemically like aliphatic chains, and aromatic compounds, which contain the specially stable benzene ring and its derivatives. This classification, together with the idea of functional groups, allows the millions of organic compounds to be studied in an orderly way.

Q2. Describe the hybridization of carbon with examples.

Hybridization is the mixing of a carbon atom's one 2s and some 2p orbitals to give a set of equivalent hybrid orbitals that point in definite directions. In sp^3 hybridization the 2s orbital mixes with all three 2p orbitals to give four sp^3 orbitals directed to the corners of a tetrahedron at 109.5°; carbon then forms four single (σ) bonds, as in methane, CH_4. In sp^2 hybridization the 2s orbital mixes with two 2p orbitals to give three sp^2 orbitals in a plane at 120°, while the leftover p-orbital forms a π-bond; this gives a carbon–carbon double bond, as in ethene, C_2H_4. In sp hybridization the 2s orbital mixes with only one 2p orbital to give two sp orbitals pointing in opposite directions at 180°, while the two leftover p-orbitals form two π-bonds; this gives a triple bond, as in ethyne, C_2H_2. Thus the type of hybridization decides the shape of the molecule and the number of multiple bonds.

Q3. Distinguish between addition, substitution and elimination reactions with examples.

These are the three most important classes of organic reaction. In an addition reaction, atoms or groups are added across a carbon–carbon double or triple bond, so an unsaturated compound becomes more saturated; for example, ethene reacts with hydrogen to give ethane ($CH_2{=}CH_2 + H_2 \rightarrow CH_3{-}CH_3$). In a substitution reaction, an atom or group in a molecule is replaced by another atom or group; saturated compounds such as alkanes undergo this, as when methane reacts with chlorine to give chloromethane and hydrogen chloride ($CH_4 + Cl_2 \rightarrow CH_3Cl + HCl$). In an elimination reaction, a small molecule such as water or a hydrogen halide is removed from a molecule to create a double bond; for example, the dehydration of ethanol gives ethene. Recognising which class a reaction belongs to helps predict the products.

10. Multiple Choice Questions (MCQs)

1. Organic chemistry is the chemistry of:
(A) Nitrogen (B) Carbon (C) Silicon (D) Sulphur

2. The general formula of alkanes is:
(A) C_nH_{2n} (B) C_nH_{2n+2} (C) C_nH_{2n-2} (D) C_nH_n

3. Carbon in methane is:
(A) sp (B) sp^2 (C) sp^3 (D) dsp^2

4. The bond angle in ethene (sp^2) is about:

(A) 109.5° (B) 120° (C) 180° (D) 90°

5. A group that gives a molecule its characteristic properties is a:
(A) radical (B) functional group (C) isomer (D) catalyst

6. Compounds with the same formula but different structures are:
(A) allotropes (B) isomers (C) homologues (D) polymers

7. $CH_4 + Cl_2 \rightarrow CH_3Cl + HCl$ is a:
(A) addition (B) substitution (C) elimination (D) polymerisation

8. Members of a homologous series differ by:
(A) $-CH_3$ (B) $-CH_2-$ (C) –OH (D) –H

9. The benzene ring is characteristic of ___ compounds:
(A) aliphatic (B) alicyclic (C) aromatic (D) saturated

10. Which is unsaturated?
(A) Ethane (B) Ethene (C) Methane (D) Propane

MCQ Answer Key

1-B 2-B 3-C 4-B 5-B 6-B 7-B 8-B 9-C 10-B

11. Quick Revision / Summary

- Carbon: catenation + multiple bonds → millions of compounds.
- Sources: coal, petroleum, natural gas.
- Classification: aliphatic (open) vs cyclic (alicyclic, aromatic); saturated vs unsaturated.
- Functional group decides properties; homologous series differ by $-CH_2-$.
- Hybridization: sp^3 (109.5°, single), sp^2 (120°, double), sp (180°, triple).
- Reactions: addition (unsaturated), substitution (saturated), elimination (forms C=C).

12. Exam Tips

Teacher's Note

Learn the three hybridizations with example, shape and angle — a guaranteed question.
Memorise general formulas: alkane C_nH_{2n+2}, alkene C_nH_{2n}, alkyne C_nH_{2n-2}.
Match reaction type to compound: unsaturated → addition, saturated → substitution.
Give a clear example for functional group and homologous series definitions.
Practise drawing structural isomers of C_4H_{10} and C_5H_{12}.