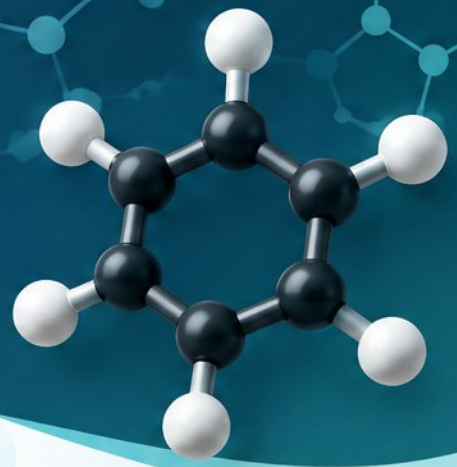
Carbon Compounds:
An Introduction to Organic Chemistry



Goals: explain carbon's bonding, classify functional groups, name simple molecules, predict basic reactions

For middle/high school students, university beginners, science teachers, and self-learners—no prior organic chemistry assumed

Roadmap: bonding and shapes → hydrocarbons → functional groups → isomerism → naming and drawing → reactions → applications → review

Approach: concept-first explanations, worked examples, everyday anchors (fuels, plastics, medicines, foods), short self-check questions

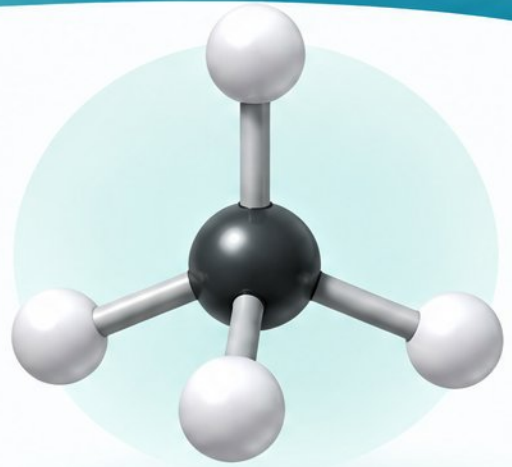
Mindset: a few recurring ideas applied to millions of molecules—build a mental model, don't memorize lists

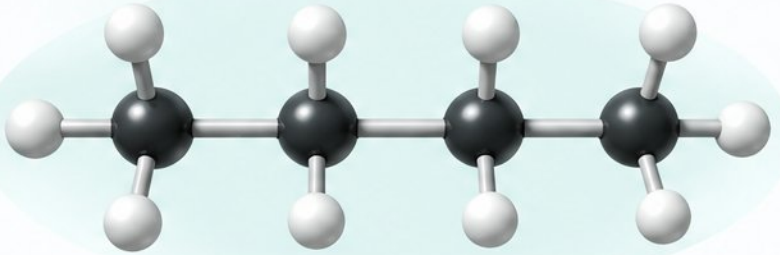


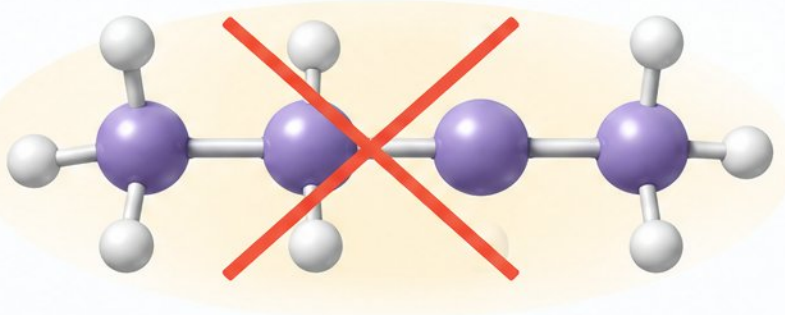


Why Carbon? Tetravalence, Catenation, and the Bonding Toolkit

- **Carbon:** $1s^2\ 2s^2\ 2p^2$ — four valence electrons shared, never gained or lost
- **Tetravalence:** every stable carbon forms four bonds (double = 2, triple = 3)
- **Catenation:** strong C–C bonds (≈348 kJ/mol) build chains, branches, rings
- **Kekulé and Couper (1858)** proposed tetravalence and chains; rings followed in 1865
- **Silicon falls short:** weak Si–Si bonds (≈226 kJ/mol) favor Si–O instead

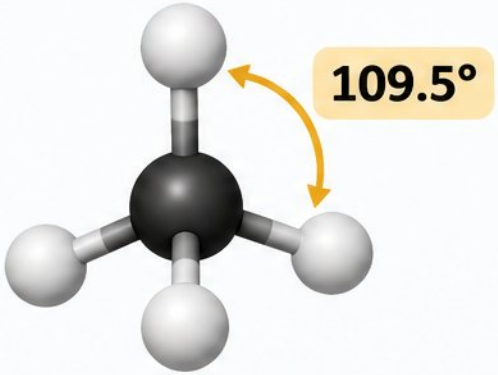






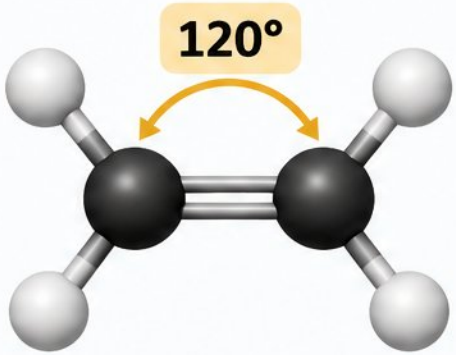
Three Shapes Around Carbon: sp^3, sp^2, and sp

sp^3: Tetrahedral



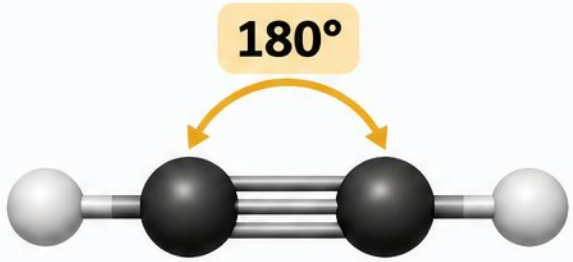
Methane (CH_4)

sp^2: Planar



Ethene (C_2H_4)

sp: Linear



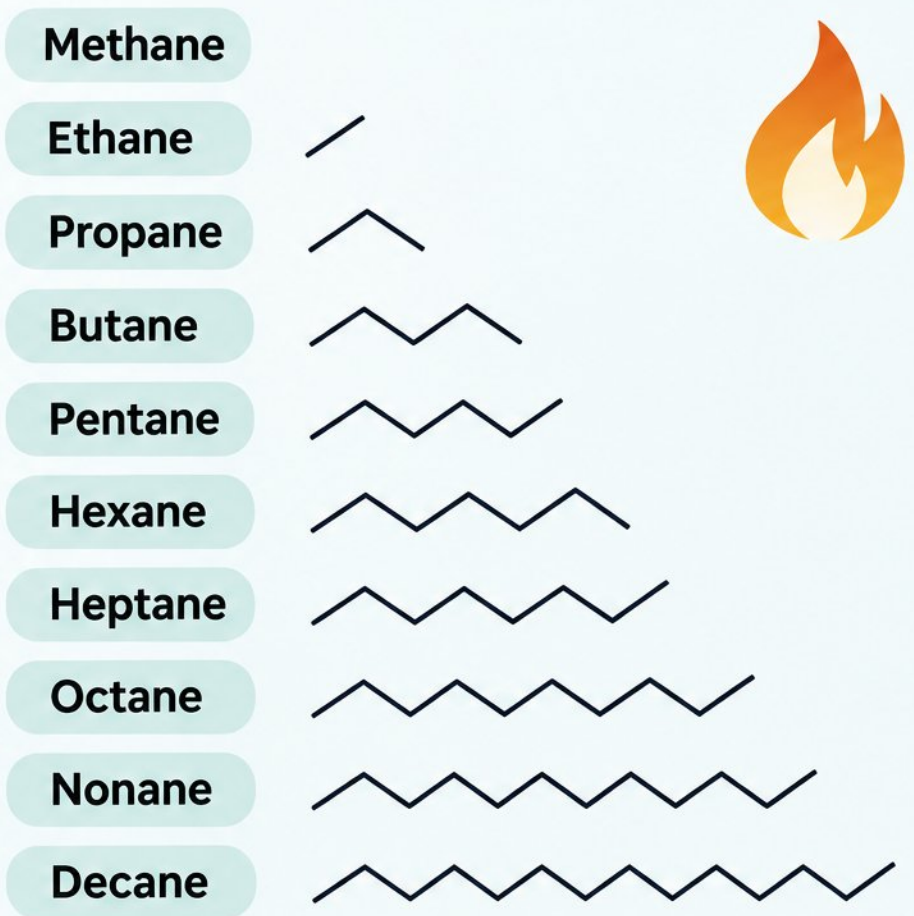
Ethyne (C_2H_2)

- Count σ bonds: 4 → sp^3 tetrahedral, 109.5°; 3 σ + 1 π → sp^2 planar, 120°; 2 σ + 2 π → *sp* linear, 180°
- Hybridization is bookkeeping; all four C–H bonds in methane are identical
- More *s* character means shorter, stronger bonds: C–C 154 > 134 > 120 pm
- Double bonds lock atoms in a plane—no free rotation, origin of *cis*–*trans* isomerism
- Saturated carbons are locally tetrahedral, so carbon skeletons zig-zag

Hydrocarbons I: Alkanes and the Homologous Series

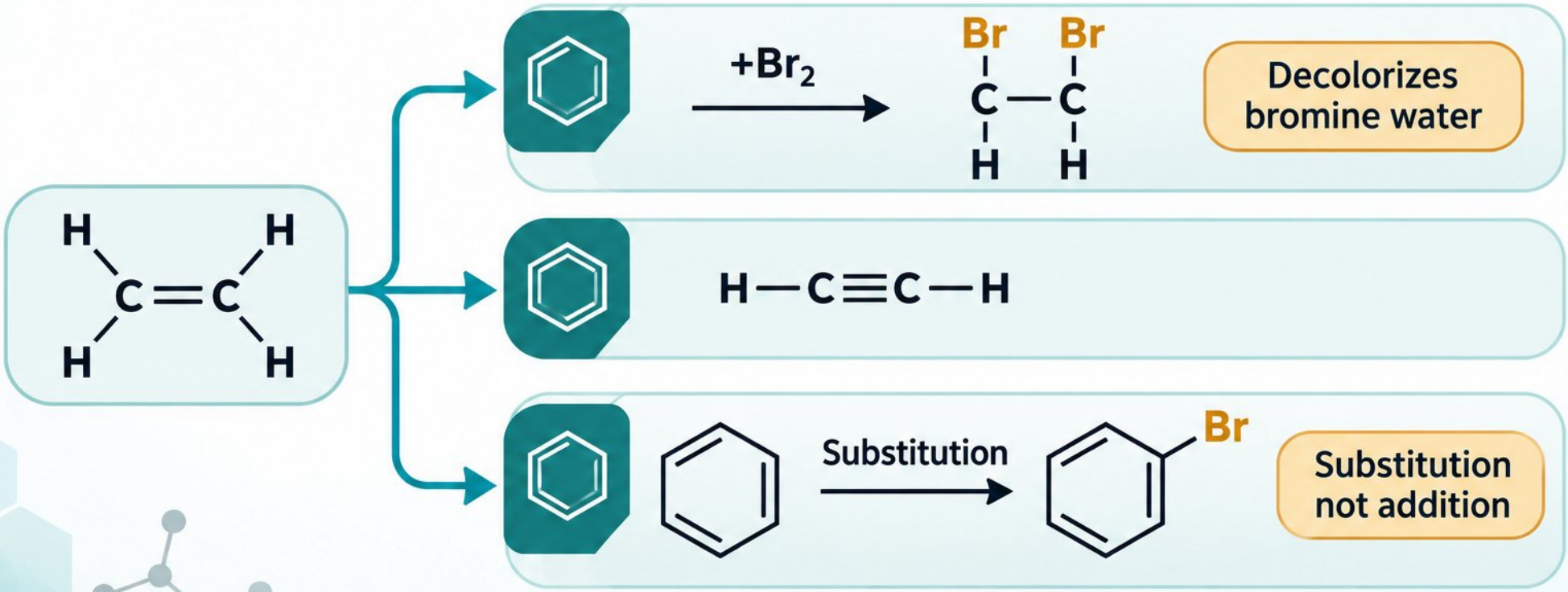
- Hydrocarbons contain only carbon and hydrogen; alkanes are saturated with formula C_nH_{2n+2}
- Parent chains: methane, ethane, propane, butane, pentane, hexane, heptane, octane, nonane, decane
- Low reactivity toward acids, bases, oxidants; burn readily and undergo UV-driven free-radical substitution
- Examples: $CH_4 + Cl_2 \rightarrow CH_3Cl + HCl$; $C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$
- Everyday anchors: natural gas (methane), LPG (propane), lighters (butane); branched alkanes raise octane rating

Alkanes C_nH_{2n+2}



Hydrocarbons II: Alkenes, Alkynes, and Aromatic Rings

- Alkenes (C_nH_{2n}): one C=C double bond; alkynes (C_nH_{2n-2}): one C≡C triple bond
- Both unsaturated, reactive at the multiple bond
- Suffixes: -ane single, -ene double, -yne triple; number to give multiple bond lowest locant
- Addition across C=C: $+H_2$/Ni → alkane; $+Br_2$ → dibromide (decolorizes bromine water)
- $+H_2O/H^+$ → alcohol; benzene planar, delocalized π, substitution not addition

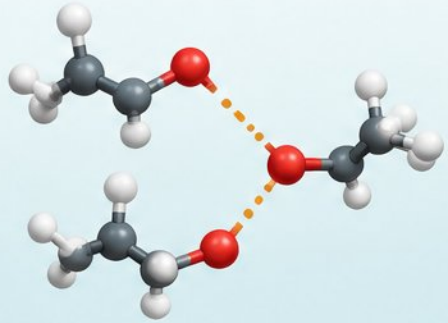


Functional Groups: Why They Define Reactivity

- A functional group is a group of atoms with characteristic chemical behavior
- Same group, same reactions: ethylene and menthene both add Br_2 across C=C
- Key families: alcohols –OH, ethers R–O–R′, aldehydes –CHO, ketones C=O, carboxylic acids –COOH, esters –COOR, amines $–NH_2$, amides $–CONH_2$, alkyl halides –X
- Carbonyl C=O appears in aldehydes, ketones, acids, esters, amides; carbon $\delta+$, oxygen $\delta-$
- Hydrogen bonding raises boiling points: ethanol 78 °C vs ethane –88 °C
- Everyday: ethanol, acetone, acetic acid (5% vinegar), ethyl acetate, fishy amines

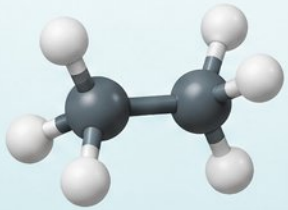
Ethanol

$CH_3–CH_2–OH$



Ethane

$CH_3–CH_3$



Boiling Point





Fuels



Plastics



Medicines



Foods

Isomerism: Same Formula, Different Molecules

- Isomers: same molecular formula, different arrangement—distinct substances with different properties
- Structural isomers differ in connectivity: chain (butane vs 2-methylpropane, C_4H_{10})
- Position isomers: propan-1-ol vs propan-2-ol (C_3H_8O); functional group isomers: ethanol vs dimethyl ether
- Stereoisomers share connectivity but differ in 3D: *cis-*/*trans*-2-butene and lactic acid enantiomers
- *Cis–trans* needs C=C plus two different groups on each carbon; but-1-ene has none
- Chiral center: carbon bonded to four different groups; enantiomers rotate polarized light oppositely

Cis-/Trans-2-Butene (Stereoisomers)

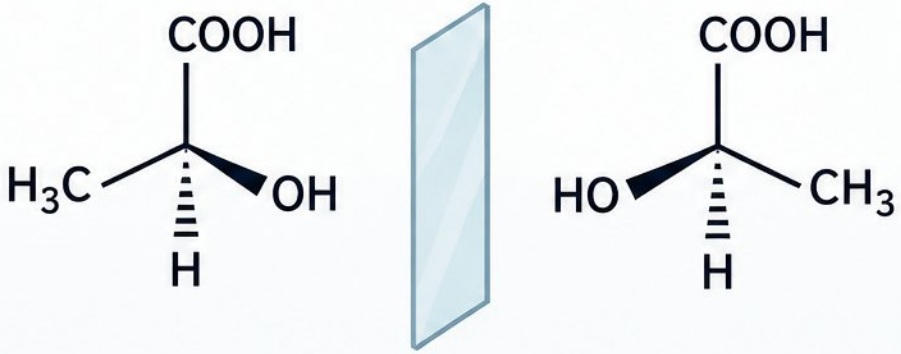


cis-2-butene



trans-2-butene

Lactic Acid Enantiomers (Chiral Center)



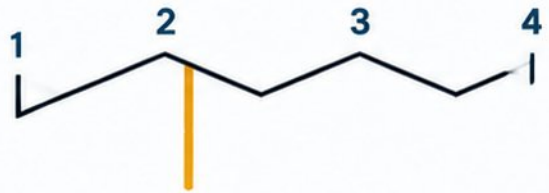
Naming Simple Organic Molecules with IUPAC Rules

- **Five-step recipe: longest chain with principal group → highest priority → lowest locant → prefix others → alphabetical order**

1. Longest Chain with Principal Group
2. Highest Priority
3. Lowest Locant
4. Prefix Others
5. Alphabetical Order

- **Priority:** carboxylic acid > ester > amide > nitrile > aldehyde > ketone > alcohol > amine > alkene > alkane

Worked example: $CH_3–CH(CH_3)–CH_2–CH_3$ → 2-methylbutane



2-methylbutane

Worked example: $HO–CH_2–CH_2–CHO$ → 3-hydroxypropanal (aldehyde beats alcohol)



3-hydroxypropanal

- **Pitfalls:** two suffixes, wrong numbering, missing *cis*/trans or R/S labels

Drawing Conventions: Condensed, Full, and Skeletal Formulas

- Four ways to draw one molecule: molecular, condensed, full Lewis, skeletal
- Skeletal formulas: each vertex and end is a carbon; C–H hydrogens are hidden
- Show H on heteroatoms (O, N); use wedges and dashes to show 3D

Worked example: 2-methylbutan-2-ol in full, condensed, and skeletal forms

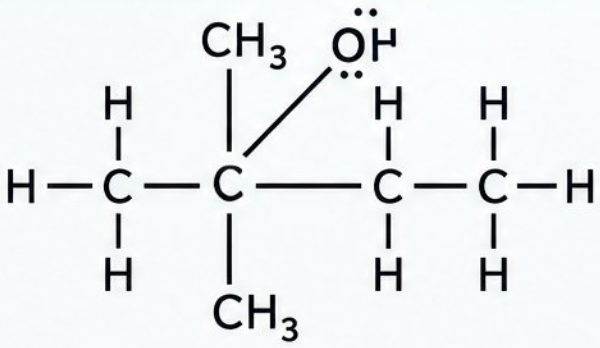
Molecular Formula

$C_5H_{12}O$

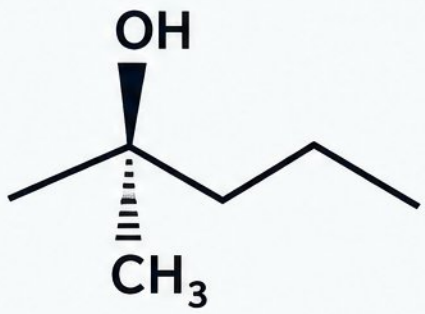
Condensed Formula

$CH_3C(CH_3)(OH)CH_2CH_3$

Full Lewis Structure



Skeletal (Line-Angle) Formula



Practice: redraw any IUPAC name in at least two correct representations

Reaction Patterns I: Substitution, Addition, and Elimination

- **Substitution:** one group replaces another; two products formed
- **Addition:** two reactants join into one product across a C=C
- **Elimination:** one reactant splits, removing a small molecule and forming C=C

Substitution

Alkane substitution: $CH_3CH_3 + Br_2 \rightarrow CH_3CH_2Br + HBr$ (UV light)



Addition

Alkene addition: $CH_2=CH_2 + Br_2 \rightarrow CH_2BrCH_2Br$ (decolorizes bromine water)



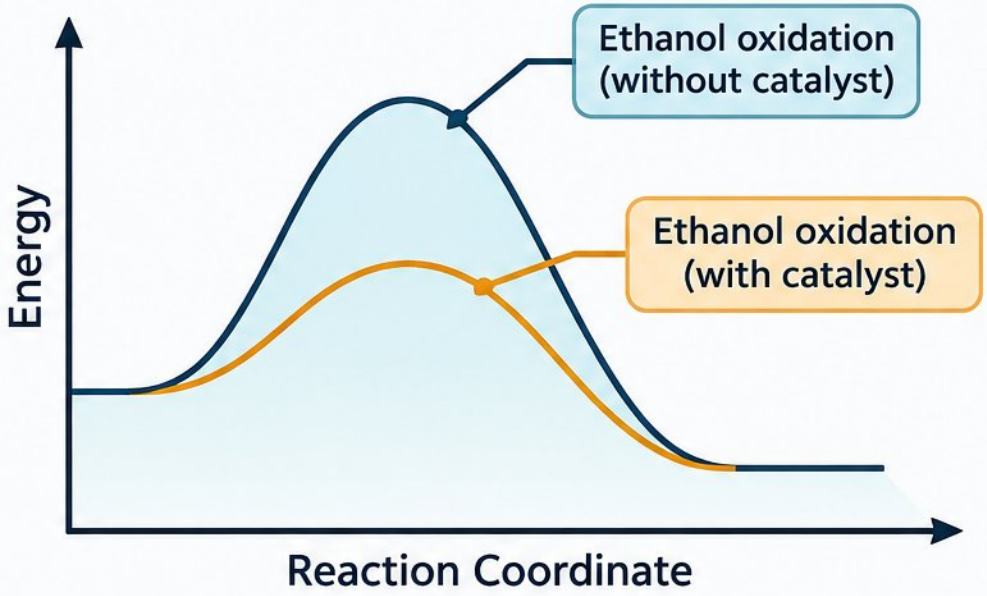
Elimination

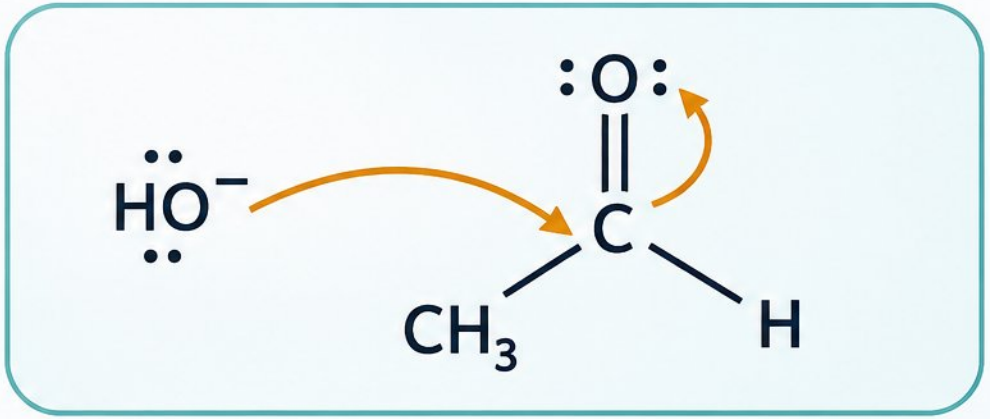
Elimination reverses addition: bromoethane + KOH/ethanol/heat → ethene + HBr



Reaction Patterns II: Oxidation, Reduction, and Curved-Arrow Basics

- Oxidation: more C–O bonds, fewer C–H bonds; reduction does the reverse
- Ethanol → ethanal → ethanoic acid; propan-2-ol gives propanone
- Nucleophiles donate electrons; electrophiles accept them
- Curved arrows track electron flow from nucleophile to electrophile
- Catalysts lower activation energy; esterification and hydrolysis are reversible





Organic Chemistry in Everyday Life and Industry



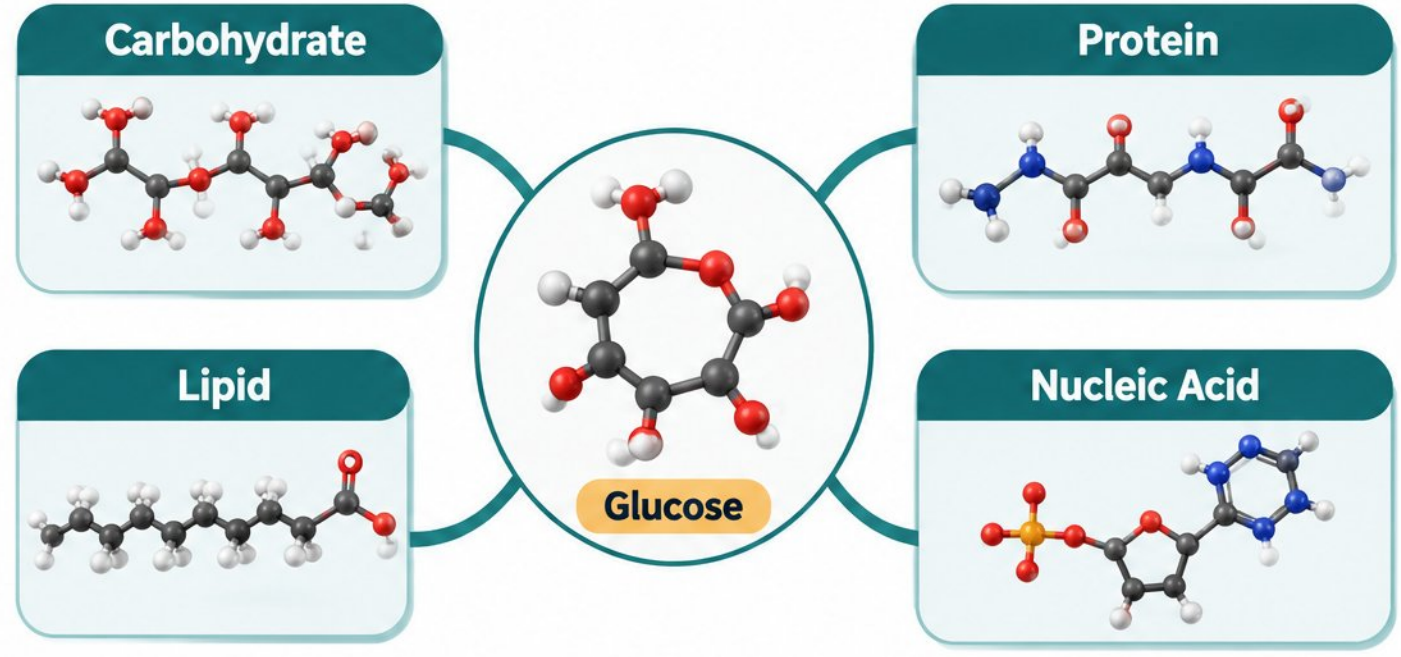




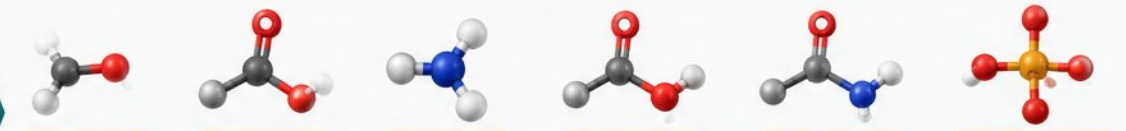
- **Fuels:** fractional distillation of petroleum gives natural gas, gasoline, kerosene, diesel, lubricating oils
- **Polymers:** polyethylene bags and bottles, PVC pipes, nylon and polyester fabrics, Kevlar vests, cellulose
- **Pharmaceuticals:** over 90% of drugs are small organic molecules; aspirin, paracetamol, antihistamines
- **Agriculture and consumer goods:** urea fertilizer, herbicides, preservatives, sweeteners, soaps, detergents, fragrances
- **Crude oil to products:** distillation, cracking, reforming; octane rating rises with branching and aromatics

Biomolecules and Green Chemistry: Where Carbon Chemistry Goes Next

- Four biomolecule classes: carbohydrates, lipids, proteins, nucleic acids
- Same functional groups recur: –OH, –COOH, –NH_2, ester and amide bonds
- Enzymes: selective chiral catalysts; enantiomers can act differently in biology
- Green chemistry: safer design, atom economy, E-factor, lower carbon footprint
- 2024–2026: biomass feedstocks, biocatalysis, continuous flow, ibuprofen in three catalytic steps
- Classroom link: carbon cycle ties combustion, photosynthesis, and organic matter

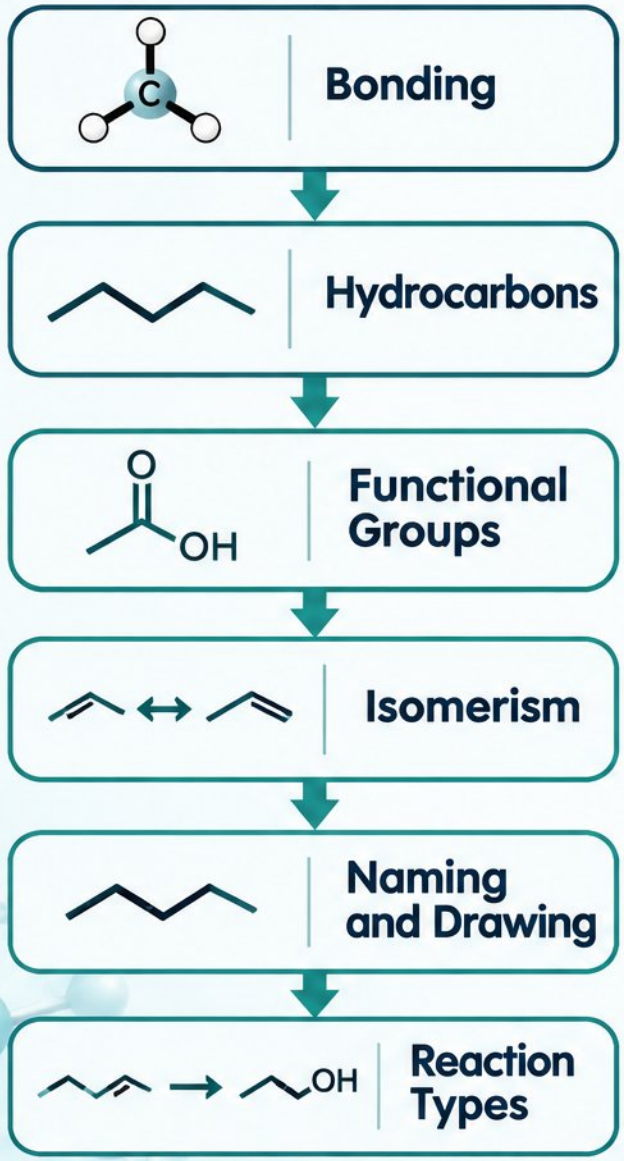


Shared Functional Groups





Review, Practice, and Your Next Steps



- **Concept map:** bonding → hydrocarbons → functional groups → isomerism → naming → reactions
- **Fix misconceptions:** count bonds not attached atoms; one suffix only; but-1-ene has no cis/trans
- **Practice:** name/draw three molecules, spot functional groups, classify reactions, check chirality
- **Self-check:** explain carbon's uniqueness, name simple molecules, predict addition and oxidation products
- **Next:** daily nomenclature drills, curved-arrow mechanisms, then biochemistry or polymer chemistry

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