Chapter 4: Carbon and its Compounds

Comprehensive Study Notes

Introduction

Carbon is one of the most versatile elements in nature, forming the basis of all living organisms and countless everyday materials. Despite constituting only 0.02% of Earth's crust and 0.03% of the atmosphere, carbon's unique properties make it extraordinarily important.

Why is carbon special?

- Forms millions of known compounds
- Basis of all living structures
- Present in food, clothes, medicines, fuels
- Shows unique bonding characteristics

4.1 Bonding in Carbon - The Covalent Bond

4.1.1 Why Carbon Forms Covalent Bonds

Electronic Configuration of Carbon:

- Atomic number: 6
- Electronic configuration: 2, 4
- Valence electrons: 4

Why not ionic bonding?

- **Gaining 4 electrons (C^{4-}):** Difficult for nucleus (6 protons) to hold 10 electrons
- **Losing 4 electrons (C^{4+}):** Requires enormous energy to remove 4 electrons

Solution: Carbon shares electrons to achieve noble gas configuration

4.1.2 Formation of Covalent Bonds

Single Covalent Bond

Hydrogen molecule (H_2):

- Each H atom has 1 electron
- Needs 1 more for complete K shell
- Share 1 pair of electrons
- H : H → H—H

Double Covalent Bond

Oxygen molecule (O_2):

- Each O atom has 6 valence electrons
- Needs 2 more for octet
- Share 2 pairs of electrons
- O :: O → O=O

Triple Covalent Bond

Nitrogen molecule (N_2):

- Each N atom has 5 valence electrons
- Needs 3 more for octet

- Share 3 pairs of electrons
- N ::: N → N≡N

4.1.3 Properties of Covalent Compounds

Property	Covalent Compounds	Ionic Compounds
Melting/Boiling Points	Low	High
Electrical Conductivity	Poor	Good (in solution/molten)
Inter-molecular Forces	Weak	Strong
State at Room Temperature	Gases/Liquids/Low melting solids	Solids

Examples from Table 4.1:

- Methane (CH_4): MP = 90K, BP = 111K
- Ethanol (C_2H_5OH): MP = 156K, BP = 351K
- Acetic acid (CH_3COOH): MP = 290K, BP = 391K

4.2 Allotropes of Carbon

4.2.1 Diamond Structure

- **Bonding:** Each carbon bonded to 4 other carbons
- **Structure:** Rigid 3D tetrahedral network
- **Properties:** Hardest natural substance, non-conductor
- **Uses:** Jewelry, cutting tools, drilling

4.2.2 Graphite Structure

- **Bonding:** Each carbon bonded to 3 other carbons in same plane

- **Structure:** Hexagonal layers stacked on top of each other
- **Properties:** Smooth, slippery, conducts electricity
- **Uses:** Pencil lead, lubricant, electrodes

4.2.3 Fullerenes

- **Discovery:** C_{60} molecule shaped like football
- **Named after:** Buckminster Fuller (architect)
- **Structure:** Carbon atoms arranged in geodesic dome pattern
- **Applications:** Nanotechnology, materials science

Key Point: Same element (carbon) with different structures leads to vastly different properties.

4.3 Versatile Nature of Carbon

4.3.1 Catenation

Definition: Carbon's unique ability to form bonds with other carbon atoms

Features:

- Forms long chains, branched chains, rings
- Carbon-carbon bonds are very strong and stable
- No other element shows catenation to this extent
- Silicon forms chains of only 7-8 atoms (very reactive)

4.3.2 Tetravalency

Carbon's Bonding Capacity:

- Valency of 4

- Can bond with 4 other atoms
- Forms bonds with C, H, O, N, S, Cl, and other elements
- Small atomic size makes bonds very strong

4.3.3 Saturated vs Unsaturated Compounds

Saturated Compounds

- **Definition:** Only single bonds between carbon atoms
- **General formula for alkanes:** C_nH_{2n+2}
- **Properties:** Less reactive, stable
- **Examples:** Methane (CH_4), Ethane (C_2H_6)

Unsaturated Compounds

- **Definition:** Contains double or triple bonds
- **Types:**
  - Alkenes (double bonds): C_nH_{2n}
  - Alkynes (triple bonds): C_nH_{2n-2}
- **Properties:** More reactive than saturated compounds
- **Examples:** Ethene (C_2H_4), Ethyne (C_2H_2)

4.4 Carbon Compound Classification

4.4.1 Hydrocarbons

Definition: Compounds containing only carbon and hydrogen

Types:

1. **Alkanes (Saturated):**
    - General formula: C_nH_{2n+2}
    - Examples: Methane, Ethane, Propane, Butane
2. **Alkenes (Unsaturated with double bonds):**
    - General formula: C_nH_{2n}
    - Examples: Ethene, Propene, Butene
3. **Alkynes (Unsaturated with triple bonds):**
    - General formula: C_nH_{2n-2}
    - Examples: Ethyne, Propyne, Butyne

4.4.2 Structural Isomerism

Definition: Compounds with same molecular formula but different structures

Example - Butane (C_4H_{10}):

1. **n-Butane:** C—C—C—C (straight chain)
2. **Isobutane:** C—C(C)—C (branched chain)

Both have formula C_4H_{10} but different properties.

4.4.3 Cyclic Compounds

Examples:

- **Cyclohexane (C_6H_{12}):** Saturated ring
- **Benzene (C_6H_6):** Unsaturated ring with special stability

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4.5 Functional Groups

4.5.1 Definition

Functional Group: Atom or group of atoms that determines chemical properties of organic compounds

4.5.2 Important Functional Groups

Class	Functional Group	Formula	Example
Haloalkane	—Cl, —Br	—X	Chloropropane
Alcohol	—OH	—OH	Propanol
Aldehyde	—CHO	—CHO	Propanal
Ketone	—CO—	>C=O	Propanone
Carboxylic Acid	—COOH	—COOH	Propanoic acid

4.5.3 Homologous Series

Definition: Series of compounds with same functional group but differing by —CH_2— unit

Characteristics:

1. Same general formula
2. Same chemical properties
3. Gradation in physical properties
4. Differ by 14u in molecular mass (—CH_2—)

Example - Alcohol Series:

- Methanol: CH_3OH (32u)
- Ethanol: C_2H_5OH (46u)

- Propanol: C_3H_7OH (60u)
- Butanol: C_4H_9OH (74u)

4.6 Nomenclature of Carbon Compounds

4.6.1 IUPAC Naming Rules

Steps:

1. **Identify longest carbon chain**
2. **Number carbon atoms** from the end nearest to functional group
3. **Add appropriate prefix/suffix** for functional group

4.6.2 Naming Examples

Compound Type	Suffix/Prefix	Example	IUPAC Name
Alkanes	-ane	C_3H_8	Propane
Alkenes	-ene	C_3H_6	Propene
Alkynes	-yne	C_3H_4	Propyne
Alcohols	-ol	C_3H_7OH	Propanol
Aldehydes	-al	C_3H_6O	Propanal
Ketones	-one	C_3H_6O	Propanone
Carboxylic Acids	-oic acid	$C_3H_6O_2$	Propanoic acid
Haloalkanes	chloro-, bromo-	C_3H_7Cl	Chloropropane

4.7 Chemical Properties of Carbon Compounds

4.7.1 Combustion Reactions

Complete Combustion: Carbon compound + O_2 → CO_2 + H_2O + Heat + Light

Examples:

1. **Methane:** $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$
2. **Ethanol:** $C_2H_5OH + 3O_2 \rightarrow 2CO_2 + 3H_2O$

Flame Characteristics:

- **Saturated hydrocarbons:** Clean blue flame
- **Unsaturated hydrocarbons:** Yellow sooty flame
- **Insufficient oxygen:** Incomplete combustion → carbon soot

Practical Application: Gas stoves have air inlets for complete combustion

4.7.2 Oxidation Reactions

Alcohol to Carboxylic Acid: Using alkaline $KMnO_4$ or acidified $K_2Cr_2O_7$ as oxidizing agents

Example: $CH_3CH_2OH + [O] \rightarrow CH_3COOH + H_2O$ (Ethanol → Ethanoic acid)

Test: $KMnO_4$ color disappears initially, persists when excess added

4.7.3 Addition Reactions (Unsaturated Compounds)

Hydrogenation: Alkene + H_2 → Alkane (in presence of Ni/Pd catalyst)

Example: $CH_2{=}CH_2 + H_2 \rightarrow CH_3{-}CH_3$ (Ethene + Hydrogen → Ethane)

Industrial Application: Hydrogenation of vegetable oils

- Converts liquid oils to solid fats
- Uses nickel catalyst
- Saturated fats vs unsaturated fats health debate

4.7.4 Substitution Reactions (Saturated Compounds)

Chlorination in Sunlight: $CH_4 + Cl_2 \rightarrow CH_3Cl + HCl$ (Methane + Chlorine → Chloromethane + HCl)

Characteristics:

- Requires sunlight
- Hydrogen atoms replaced by chlorine
- Multiple products possible with higher alkanes

4.8 Important Carbon Compounds

4.8.1 Ethanol (C_2H_5OH)

Physical Properties:

- Liquid at room temperature
- Soluble in water in all proportions
- Pleasant smell
- MP: 156K, BP: 351K

Uses:

- Active ingredient in alcoholic beverages
- Solvent in medicines (tincture iodine, cough syrups)
- Industrial solvent

- Fuel additive (cleaner than petrol)

Chemical Reactions:

1. **With Sodium:** $2Na + 2C_2H_5OH \rightarrow 2C_2H_5ONa + H_2$ (Sodium ethoxide + Hydrogen gas)
2. **Dehydration (Elimination):** $C_2H_5OH \rightarrow C_2H_4 + H_2O$ (Hot conc. H_2SO_4 at 443K)
3. **Oxidation:** $C_2H_5OH + [O] \rightarrow CH_3COOH + H_2O$

Safety Information:

- **Ethanol:** Causes drunkenness, long-term health problems
- **Methanol:** Extremely toxic, causes blindness, death
- **Denatured alcohol:** Ethanol made unfit for drinking by adding methanol and dyes

4.8.2 Ethanoic Acid (CH_3COOH)

Physical Properties:

- Liquid at room temperature
- MP: 290K (freezes in winter - "glacial acetic acid")
- Sour taste and smell
- Soluble in water

Uses:

- Vinegar (5-8% solution) for food preservation
- Industrial chemical synthesis
- Pharmaceutical industry

Chemical Reactions:

1. **Esterification:** $CH_3COOH + C_2H_5OH \rightarrow CH_3COOC_2H_5 + H_2O$ (Acid + Alcohol → Ester + Water)
   - Requires acid catalyst (conc. H_2SO_4)
   - Esters are sweet-smelling (perfumes, flavoring)
2. **With Base (Neutralization):** $CH_3COOH + NaOH \rightarrow CH_3COONa + H_2O$ (Sodium acetate + Water)
3. **With Carbonates:** $2CH_3COOH + Na_2CO_3 \rightarrow 2CH_3COONa + H_2O + CO_2$ $CH_3COOH + NaHCO_3 \rightarrow CH_3COONa + H_2O + CO_2$
4. **Saponification:** Ester + NaOH → Alcohol + Sodium salt of acid (Used in soap making)

Acid Strength:

- **Weak acid:** Partially ionizes in water
- **Comparison:** HCl (strong) vs CH_3COOH (weak)
- **Test:** Universal indicator shows different pH values

4.9 Soaps and Detergents

4.9.1 Structure and Composition

Soaps

- **Chemical nature:** Sodium/potassium salts of long-chain carboxylic acids
- **Structure:** Long hydrocarbon chain + ionic head
- **Example:** $C_{17}H_{35}COONa$ (sodium stearate)

Detergents

- **Chemical nature:** Sodium salts of sulphonic acids or ammonium salts
- **Structure:** Long hydrocarbon chain + charged head

- **Advantage:** Work in hard water

4.9.2 Cleaning Mechanism

Micelle Formation:

1. **Hydrophilic head:** Ionic end interacts with water
2. **Hydrophobic tail:** Carbon chain interacts with oil/dirt
3. **Micelle structure:** Tails inside, heads outside
4. **Emulsification:** Oil dirt trapped in micelle center
5. **Removal:** Micelles with dirt washed away with water

Soap vs Hard Water:

- **Problem:** Ca^{2+}, Mg^{2+} ions react with soap
- **Reaction:** $2C_{17}H_{35}COONa + Ca^{2+} \rightarrow (C_{17}H_{35}COO)_2Ca + 2Na^+$
- **Result:** Insoluble precipitate (scum formation)
- **Solution:** Use detergents (don't precipitate with Ca^{2+}, Mg^{2+})

4.10 Formation and Sources

4.10.1 Fossil Fuels

Coal Formation:

- **Origin:** Remains of ancient trees, ferns, plants
- **Process:** Buried under earth → pressure → heat → coal
- **Time scale:** Millions of years
- **Current use:** Major fuel source

Petroleum Formation:

- **Origin:** Remains of tiny marine plants and animals
- **Process:** Died → sea bed → covered by silt → bacteria action → oil/gas
- **Conditions:** High pressure underground
- **Storage:** Trapped in porous rocks

Why called fossil fuels? Formed from ancient organic matter (fossils)

4.10.2 Environmental Impact

Combustion Problems:

- **Incomplete combustion:** Produces carbon monoxide (toxic)
- **Nitrogen/sulfur impurities:** Form acid rain (NO_2, SO_2)
- **Carbon dioxide:** Greenhouse gas, climate change
- **Soot formation:** Air pollution from unsaturated compounds

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4.11 Flame Types and Combustion

4.11.1 Flame Colors and Causes

Blue Flame:

- **Cause:** Complete combustion with sufficient oxygen
- **Products:** $CO_2 + H_2O$
- **Example:** Gas stove with open air holes

Yellow Sooty Flame:

- **Cause:** Incomplete combustion, insufficient oxygen
- **Products:** Carbon particles (soot) + CO_2 + H_2O
- **Example:** Blocked air holes in gas stove

Luminous Flame:

- **Cause:** Gaseous substances burning and glowing
- **Color depends on:** Element present
- **Example:** Copper wire in flame gives green color

4.11.2 Flame vs No Flame

- **With flame:** Gaseous substances burn
- **Without flame:** Solid substances (coal, charcoal) glow red
- **Wood burning:** Initially flames (volatile substances), then glowing (carbon)

4.12 Nomenclature System

4.12.1 Root Names (Carbon Chain Length)

Carbon Atoms	Root Name	Example
1	Meth-	Methane
2	Eth-	Ethane
3	Prop-	Propane
4	But-	Butane
5	Pent-	Pentane
6	Hex-	Hexane

4.12.2 Functional Group Modifications

Rules:

- If suffix starts with vowel, remove 'e' from alkane name
- Examples:
  - Propane + one → Propanone
  - Propane + ol → Propanol
  - Propane + oic acid → Propanoic acid

Practice Questions and Answers

Q1. What are the two properties of carbon that lead to the formation of a large number of compounds?

Answer: The two properties are:

1. **Tetravalency:** Carbon has valency 4, allowing it to bond with four other atoms
2. **Catenation:** Carbon's unique ability to form strong bonds with other carbon atoms, creating long chains, branched chains, and rings

These properties together allow carbon to form millions of different compounds with varying chain lengths and functional groups.

Q2. How would you distinguish experimentally between an alcohol and a carboxylic acid?

Answer: Several experimental methods can be used:

1. **Litmus test:** Carboxylic acid turns blue litmus red, alcohol has no effect

2. **pH test:** Carboxylic acid has pH < 7, alcohol is neutral (pH ≈ 7)
3. **Sodium metal test:** Both react with sodium to produce hydrogen, but carboxylic acid reacts more vigorously
4. **Sodium carbonate test:** Carboxylic acid produces CO_2 gas with Na_2CO_3, alcohol doesn't react

Q3. Explain why soap does not work effectively in hard water. How do detergents overcome this problem?

Answer: Hard water contains Ca^{2+} and Mg^{2+} ions that react with soap to form insoluble precipitates (scum): $2C_{17}H_{35}COONa + Ca^{2+} \rightarrow (C_{17}H_{35}COO)_2Ca\downarrow + 2Na^+$

This precipitate reduces soap effectiveness and wastes soap. Detergents overcome this because their charged ends (sulfonate groups) do not form insoluble precipitates with Ca^{2+} and Mg^{2+} ions, allowing them to work effectively in hard water.

Q4. What is the difference between saturated and unsaturated hydrocarbons? Give a test to distinguish between them.

Answer: Saturated hydrocarbons: Contain only single bonds (C—C), general formula C_nH_{2n+2}
Unsaturated hydrocarbons: Contain double (C=C) or triple (C≡C) bonds

Test to distinguish: Add alkaline $KMnO_4$ solution:

- **Saturated:** No reaction, $KMnO_4$ remains purple
- **Unsaturated:** $KMnO_4$ gets decolorized (purple to colorless)

Alternative test: Bromine water test - unsaturated compounds decolorize bromine water.

Q5. Why are synthetic detergents better than soaps for washing clothes in hard water?

Answer: Synthetic detergents are better because:

1. **Chemical structure:** Sulphonate or ammonium-based charged ends don't precipitate with Ca^{2+}/Mg^{2+}
2. **No scum formation:** Work effectively in hard water without forming insoluble precipitates
3. **Economic advantage:** Less detergent needed compared to soap in hard water
4. **Better cleaning:** Maintain cleaning efficiency regardless of water hardness

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4.13 Key Chemical Equations

Combustion Reactions:

1. **Complete:** $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$ + Heat
2. **Incomplete:** $2CH_4 + 3O_2 \rightarrow 2CO + 4H_2O$ + Heat

Functional Group Reactions:

1. **Alcohol oxidation:** $C_2H_5OH + [O] \rightarrow CH_3COOH + H_2O$
2. **Esterification:** $CH_3COOH + C_2H_5OH \rightarrow CH_3COOC_2H_5 + H_2O$
3. **Saponification:** $C_{17}H_{35}COOC_2H_5 + NaOH \rightarrow C_{17}H_{35}COONa + C_2H_5OH$

Addition Reactions:

1. **Hydrogenation:** $C_2H_4 + H_2 \rightarrow C_2H_6$ (Ni catalyst)
2. **Halogenation:** $C_2H_4 + Br_2 \rightarrow C_2H_4Br_2$

Substitution Reactions:

1. **Chlorination:** $CH_4 + Cl_2 \rightarrow CH_3Cl + HCl$ (sunlight)

4.14 Industrial Applications

4.14.1 Petrochemical Industry

- **Raw materials:** Petroleum, natural gas
- **Products:** Plastics, synthetic fibers, pharmaceuticals
- **Processes:** Cracking, reforming, polymerization

4.14.2 Food Industry

- **Preservation:** Acetic acid in vinegar
- **Flavoring:** Esters for artificial flavors
- **Fuel:** Ethanol from sugarcane (biofuel)

4.14.3 Pharmaceutical Industry

- **Solvents:** Ethanol in medicines
- **Drug synthesis:** Functional group modifications
- **Antiseptics:** Alcohol-based sanitizers

4.15 Environmental Considerations

4.15.1 Pollution from Carbon Compounds

- **Air pollution:** Incomplete combustion products
- **Acid rain:** SO_2, NO_2 from impurities in fossil fuels
- **Greenhouse effect:** CO_2 from burning fossil fuels

4.15.2 Sustainable Alternatives

- **Biofuels:** Ethanol from plant sources
- **CNG:** Cleaner burning than petrol
- **Renewable sources:** Solar, wind to reduce fossil fuel dependence

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Chapter Summary

Carbon's unique properties of tetravalency and catenation enable it to form millions of compounds essential for life and industry. The formation of covalent bonds through electron sharing creates stable molecules with characteristic properties.

Understanding functional groups helps predict chemical behavior, while homologous series show how similar compounds can have gradual changes in physical properties. The versatile nature of carbon compounds makes them suitable for diverse applications from fuels and solvents to pharmaceuticals and cleaning agents.

The study of carbon compounds bridges chemistry with daily life, explaining everything from cooking flames to soap action, fossil fuel formation to environmental challenges. Mastering carbon chemistry provides foundation for understanding organic chemistry and biochemistry.

Study Tips:

- Practice drawing electron dot structures for different compounds
- Master nomenclature rules and functional group identification
- Understand the relationship between structure and properties
- Connect chemical reactions to practical applications
- Focus on environmental implications of carbon compound usage

Source: NCERT Science Textbook

Comprehensive study material for thorough understanding