Carbon and its Compounds

 Carbon's Importance: Carbon is a crucial element for life and many everyday materials. Though it's not abundant on Earth, its properties make it incredibly versatile.

 Where Carbon is Found:

- Earth's crust (0.02%): Exists as minerals like carbonates and hydrogencarbonates, and in fossil fuels like coal and petroleum.
- Atmosphere (0.03%): Present as carbon dioxide gas.

 Why Carbon is Special: This chapter will explore the unique properties of carbon that make it so essential.

 Carbon in Our Lives: Many things we use daily, including food, clothing, medicines, and books, are made from carbon-containing compounds. All living things are also carbon-based.

Properties of Carbon Compounds

- Unlike ionic compounds, most carbon compounds don't conduct electricity well.
- They have low melting and boiling points compared to ionic compounds.
- This suggests weak forces of attraction between the molecules.
- The bonding in these compounds doesn't create ions.

Why Carbon Forms Covalent Bonds

- Carbon has 4 valence electrons (atomic number 6).
- To achieve a stable outer shell (like a noble gas), it needs to gain or lose 4 electrons.
  - Gaining 4 electrons is difficult because the nucleus would struggle to hold the extra electrons.
  - Losing 4 electrons requires a lot of energy.
- Instead, carbon *shares* its valence electrons with other atoms (including other carbon atoms). This is called a **covalent bond**.

Examples of Covalent Bonding

- **Hydrogen (H_2):** Two hydrogen atoms share their single electrons to form a single covalent bond.
- **Chlorine (Cl_2):** Two chlorine atoms share one electron each to form a single covalent bond.
- **Oxygen (O_2):** Two oxygen atoms share two electrons each to form a double covalent bond.
- **Water (H_2O):** One oxygen atom forms single bonds with two hydrogen atoms.

- **Nitrogen (N_2):** Two nitrogen atoms share three electrons each to form a triple covalent bond.
- **Methane (CH_4):** One carbon atom shares its four valence electrons with four hydrogen atoms, forming four single bonds.

Covalent Bonds and Properties

- Covalent bonds are strong bonds *within* a molecule.
- Forces *between* molecules (intermolecular forces) are weak.
- This explains the low melting and boiling points of carbon compounds.
- Because electrons are shared and no charged particles (ions) are formed, covalent compounds generally don't conduct electricity well.

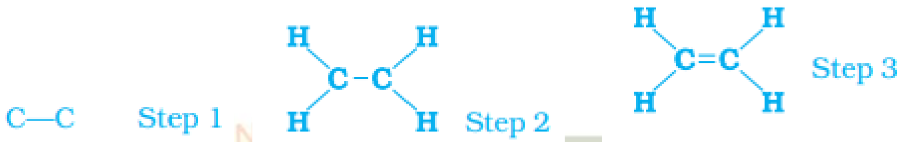
Why Carbon Forms So Many Compounds

- **Covalent Bonding:** Carbon's ability to form covalent bonds (sharing electrons) is key to its versatility.
- **Catenation:**
    - Carbon has a unique ability to form long chains and rings by bonding with other carbon atoms.
    - These chains can be straight, branched, or arranged in rings.
    - Carbon atoms in these chains can be linked by single, double, or triple bonds.
        - **Saturated compounds:** Carbon atoms linked by only single bonds.
        - **Unsaturated compounds:** Carbon atoms linked by double or triple bonds.
    - While other elements like silicon show some catenation, it's limited compared to carbon. Carbon-carbon bonds are much stronger and more stable.
- **Tetravalency:**
    - Carbon has a valency of four, meaning it can bond with four other atoms.
    - This allows it to form compounds with various elements like oxygen, hydrogen, nitrogen, sulfur, and chlorine.
    - The properties of these compounds depend on the elements involved.
- **Strong Bonds:**
    - Carbon forms strong bonds with many other elements due to its small size.
    - Its nucleus can hold shared electrons tightly.
    - Larger atoms form weaker bonds.

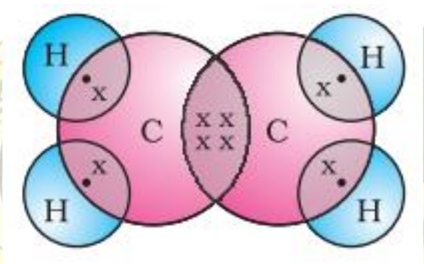
These factors together explain why carbon forms millions of compounds, far exceeding the number formed by all other elements combined!

Saturated and Unsaturated Carbon Compounds

Drawing Structures of Carbon Compounds



- **Ethane (C_2H_6)**
  1. **Connect:** Link the two carbon atoms with a single bond (C—C).
  2. **Complete:** Add three hydrogens to each carbon to satisfy remaining valencies.
- **Propane (C_3H_8)**
  1. **Connect:** Link the three carbons in a chain with single bonds (C—C—C).
  2. **Complete:** Add hydrogens to each carbon to fulfill its four bonds.
- **Ethene (C_2H_4)**
  1. **Connect:** Start with a single bond between the two carbons (C—C).
  2. **Observe:** Each carbon has one unsatisfied valency.
  3. **Form Double Bond:** Create a double bond between the carbons (C=C).
- **Ethyne (C_2H_2) **
  1. **Connect:** Start with a single bond between the two carbons (C—C).
  2. **Observe:** Each carbon has *three* unsatisfied valencies.
  3. **Form Triple Bond:** Create a triple bond between the carbons (C≡C).
  4. **Complete:** Add one hydrogen to each carbon.



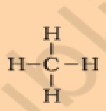
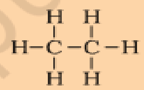
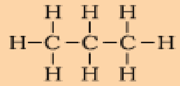
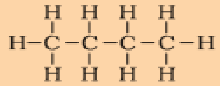
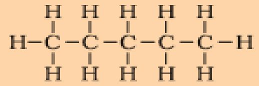
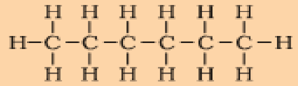
Structure of ethene

Types of Carbon Compounds

- **Saturated Compounds:**
  - Only single bonds between carbon atoms.
  - Example: Ethane, Propane
  - Generally less reactive.
- **Unsaturated Compounds:**
  - Double or triple bonds between carbon atoms.
  - Example: Ethene, Ethyne
  - More reactive than saturated compounds.

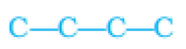
Chains, Branches and Rings

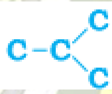
Formulae and structures of saturated compounds of carbon and hydrogen

No. of C atoms	Name	Formula	Structure
1	Methane	CH_4	
2	Ethane	C_2H_6	
3	Propane	C_3H_8	
4	Butane	C_4H_{10}	
5	Pentane	C_5H_{12}	
6	Hexane	C_6H_{14}	

Understanding Butane Structures

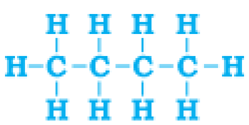
- **Butane:** A hydrocarbon with four carbon atoms (C_4H_{10}).
- **Carbon Skeletons:** Different ways to arrange the carbon atoms.
- **Two Possibilities for Butane:**
  - **Straight Chain:** All four carbons connected in a line.
  - **Branched Chain:** Three carbons in a line, with the fourth carbon attached to the middle carbon.

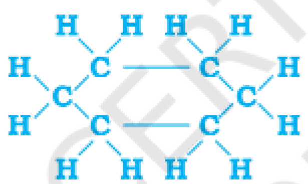




Two possible carbon skeletons.

Filling the remaining valencies with hydrogen gives us –





Complete molecules for two structures with formula C4H10

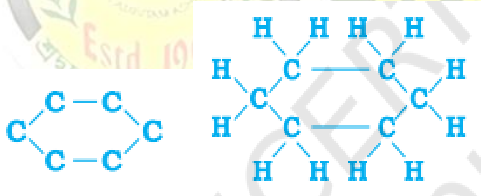
Isomers

- **Butane (C_4H_{10}):** Has two different structures (isomers) with the same molecular formula.
  - **Straight Chain:** All four carbons connected in a line.
  - **Branched Chain:** Three carbons in a line, with the fourth carbon branching off the middle carbon.
- **Structural Isomers:** Compounds with the same molecular formula but different structures.
- **Why this matters:** Isomers have different physical and chemical properties due to their varying structures.

Carbon Rings

- **Chains and Rings:** Carbon atoms can form straight chains, branched chains, *and rings*.
- **Cyclohexane (C_6H_{12}):**
  - A cyclic hydrocarbon (meaning it has a ring of carbon atoms).
  - Six carbon atoms form a ring.
  - Each carbon atom is bonded to two other carbons and two hydrogens.

This adds another dimension to the structural diversity of carbon compounds!

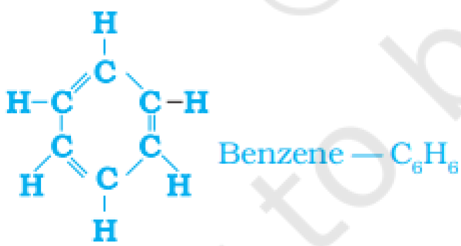


Structure of cyclohexane

(a) carbon skeleton (b) complete molecule

Hydrocarbons

- **Definition:** Compounds containing only carbon and hydrogen.
- **Types of Hydrocarbons:**
  - **Alkanes:** Saturated hydrocarbons (only single bonds between carbon atoms).
  - **Alkenes:** Unsaturated hydrocarbons with at least one double bond between carbon atoms.
  - **Alkynes:** Unsaturated hydrocarbons with at least one triple bond between carbon atoms.
- **Carbon Structures:** Hydrocarbons can have different carbon arrangements:
  - **Straight chains**
  - **Branched chains**
  - **Cyclic structures (rings)**
- **Example:** Benzene (C_6H_6) is a cyclic hydrocarbon with alternating single and double bonds between its carbon atoms.



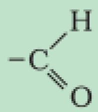
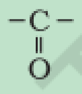
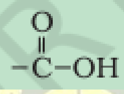
Structure of benzene

Functional Groups in Carbon Compounds

- **Carbon's Bonding:** Carbon can form bonds with other elements besides hydrogen, such as halogens (fluorine, chlorine, etc.), oxygen, nitrogen, and sulfur.
- **Heteroatoms:** When these elements replace a hydrogen atom in a hydrocarbon chain, they are called heteroatoms.
- **Functional Groups:** Heteroatoms can be part of specific groups of atoms called functional groups.
- **Impact of Functional Groups:**

    - Functional groups give special properties to the compound.
    - These properties are independent of the length and arrangement of the carbon chain.
- **Attachment:** Functional groups attach to the carbon chain by replacing one or more hydrogen atoms.
- **Free Valencies:** The single line in the structural representation of a functional group shows where it can attach to the carbon chain.

Some functional groups in carbon compounds

Hetero atom	Class of compounds	Formula of functional group
Cl/Br	Halo- (Chloro/bromo) alkane	—Cl, —Br (substitutes for hydrogen atom)
Oxygen	1. Alcohol	—OH
	2. Aldehyde	
	3. Ketone	
	4. Carboxylic acid	

Homologous Series

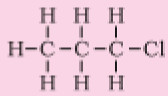
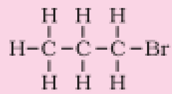
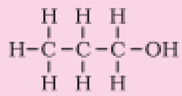
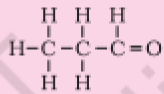
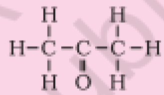
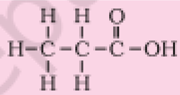
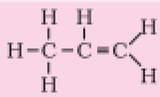
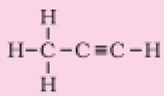
- **Definition:** A series of carbon compounds with the same functional group and similar chemical properties. Each member differs from the next by a $-CH_2-$ unit.
- **Examples:**
    - Methanol (CH_3OH), Ethanol (C_2H_5OH), Propanol (C_3H_7OH), Butanol (C_4H_9OH) all belong to the alcohol homologous series.
- **Molecular Mass Difference:**
    - The difference in molecular mass between consecutive members of a homologous series is 14u (mass of $-CH_2-$ unit).
    - Example: Methane (CH_4) and Ethane (C_2H_6) differ by 14u.
- **General Formula:**
    - **Alkanes:** C_nH_{2n+2} (where n = number of carbon atoms)
    - **Alkenes:** C_nH_{2n}
    - **Alkynes:** C_nH_{2n-2}
- **Gradation in Physical Properties:**
    - Melting and boiling points increase with increasing molecular mass within a homologous series.
    - Solubility in a particular solvent also shows a gradual change.
- **Similar Chemical Properties:**

- Chemical properties remain similar throughout a homologous series because they are determined by the functional group.

Naming Carbon Compounds (Nomenclature)

1. **Count Carbons:**
   - Identify the number of carbon atoms in the main chain. This gives you the base name (e.g., propane for 3 carbons).
2. **Functional Group Suffix/Prefix:**
   - If a functional group is present, use the correct suffix or prefix.
   - Example: -OH (alcohol) uses the suffix "-ol" (e.g., propanol).
3. **Vowel Rule:**
   - If the functional group suffix starts with a vowel (a, e, i, o, u), remove the final "e" from the base name before adding the suffix.
   - Example: propane - e + one = propanone
4. **Unsaturated Bonds:**
   - For double bonds, change the ending from "ane" to "ene" (e.g., propene).
   - For triple bonds, change the ending from "ane" to "yne" (e.g., propyne).

Nomenclature of organic compounds

Class of compounds	Prefix/Suffix	Example	
1. Halo alkane	Prefix-chloro, bromo, etc.		Chloropropane
			Bromopropane
2. Alcohol	Suffix - ol		Propanol
3. Aldehyde	Suffix - al		Propanal
4. Ketone	Suffix - one		Propanone
5. Carboxylic acid	Suffix - oic acid		Propanoic acid
6. Alkenes	Suffix - ene		Propene
7. Alkynes	Suffix - yne		Propyne

Combustion of Carbon Compounds

- **Burning Carbon:** All forms of carbon (like diamond, graphite, coal) burn in oxygen to produce carbon dioxide, heat, and light.
- **Burning Carbon Compounds:** Most carbon compounds also release significant heat and light when burned (combusted).
- **Types of Flames:**
    - **Clean Flame:** Saturated hydrocarbons usually burn with a clean flame (think of a gas stove with proper air supply).
    - **Sooty Flame:** Unsaturated hydrocarbons burn with a yellow, sooty flame due to incomplete combustion.
    - **Incomplete Combustion:** Even saturated hydrocarbons can produce a sooty flame if there's not enough oxygen.
- **Air Supply:**
    - Stoves have air inlets to ensure enough oxygen for complete combustion and a clean blue flame.
    - Blackened cooking vessels indicate blocked air holes and wasted fuel.
- **Pollution:**
    - Fuels like coal and petroleum contain nitrogen and sulfur.
    - Burning these fuels produces sulfur and nitrogen oxides, which are major air pollutants.

Oxidation of Carbon Compounds

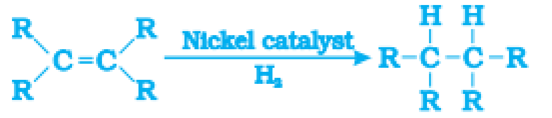
- **Combustion:** Complete oxidation of carbon compounds occurs during burning, producing carbon dioxide.
- **Oxidation of Alcohols:** Alcohols can be oxidized to carboxylic acids. This involves adding oxygen to the alcohol molecule.
    - Example: Ethanol (alcohol in wine) can be oxidized to ethanoic acid (acetic acid in vinegar).
- **Oxidizing Agents:**
    - Substances that can add oxygen to other substances are called oxidizing agents.
    - Examples: Alkaline potassium permanganate and acidified potassium dichromate are common oxidizing agents used to convert alcohols to carboxylic acids.

$$CH_3-CH_2OH \xrightarrow[\text{Or acidified } K_2Cr_2O_7 + \text{Heat}]{\text{Alkaline } KMnO_4 + \text{Heat}} CH_3COOH$$

Addition Reactions

- **Unsaturated to Saturated:** Unsaturated hydrocarbons (containing double or triple bonds) can react with hydrogen to become saturated hydrocarbons (containing only single bonds).
- **Catalysts:** This reaction requires catalysts like palladium or nickel. Catalysts speed up reactions without being consumed in the process.
- **Hydrogenation of Vegetable Oils:**
    - A common example of addition reaction.

    - Nickel catalyst is used to add hydrogen to unsaturated vegetable oils.
    - This process converts liquid oils into solid or semi-solid fats (like margarine).
- **Saturated vs. Unsaturated Fats:**
    - Vegetable oils usually have unsaturated carbon chains.
    - Animal fats have saturated carbon chains.
    - Unsaturated fats are generally considered healthier than saturated fats.



Substitution Reactions

- **Saturated Hydrocarbons:** These are generally unreactive.
- **Reaction with Chlorine:** In the presence of sunlight, saturated hydrocarbons react with chlorine.
- **Substitution:** Chlorine atoms replace hydrogen atoms in the hydrocarbon.
    - Example: Methane (CH_4) reacts with chlorine (Cl_2) to form chloromethane (CH_3Cl) and hydrogen chloride (HCl).
- **Multiple Products:** With larger hydrocarbons, many different substitution products are possible.

$$CH_4 + Cl_2 \rightarrow CH_3Cl + HCl \text{ (in the presence of sunlight)}$$

Properties of Ethanol

- **Physical Properties:**
    - Liquid at room temperature.
    - Soluble in water.
- **Common Uses:**
    - Active ingredient in alcoholic drinks.
    - Solvent in medicines (tincture iodine, cough syrups, tonics).
- **Effects of Consumption:**
    - Small amounts of diluted ethanol cause drunkenness.
    - Pure ethanol is lethal even in small quantities.
    - Long-term consumption leads to health problems.

Reactions of Ethanol

- **Reaction with Sodium:**
    - Ethanol reacts with sodium metal to produce sodium ethoxide and hydrogen gas.
    - This is similar to the reaction of water with sodium, which also produces hydrogen gas.

$$2Na + 2CH_3CH_2OH \rightarrow 2CH_3CH_2O^-Na^+ + H_2$$
(Sodium ethoxide)

- **Dehydration Reaction:**
  - Heating ethanol with concentrated sulfuric acid removes water (dehydration) and produces ethene (an unsaturated hydrocarbon).
  - Concentrated sulfuric acid acts as a dehydrating agent.

$$CH_3 - CH_2OH \xrightarrow[H_2SO_4]{\text{Hot Conc.}} CH_2 = CH_2 + H_2O$$

Properties of Ethanoic Acid

- **Common Names:**
  - Acetic acid
  - Glacial acetic acid (due to its tendency to freeze in cold climates)
- **Vinegar:** A 5-8% solution of ethanoic acid in water. Used as a preservative in pickles.
- **Carboxylic Acid:** Belongs to a group of organic compounds characterized by their acidic nature.
- **Weak Acid:** Unlike strong mineral acids (like HCl), ethanoic acid only partially ionizes in water.

Reactions of Ethanoic Acid

$$\underset{\text{(Ethanoic acid)}}{CH_3 - COOH} + \underset{\text{(Ethanol)}}{CH_3 - CH_2OH} \xrightleftharpoons{\text{Acid}} \underset{\text{(Ester)}}{CH_3 - \underset{\substack{\| \\ O}}{C} - O - CH_2 - CH_3} + H_2O$$

- **Esterification:**
  - Ethanoic acid reacts with ethanol in the presence of an acid catalyst to form an ester.
  - Esters often have a sweet smell and are used in perfumes and flavorings.

$$CH_3COOC_2H_5 \xrightarrow{NaOH} C_2H_5OH + CH_3COONa$$

- **Saponification:**
  - Esters react with sodium hydroxide (an alkali) to produce an alcohol and the sodium salt of a carboxylic acid (soap).
- **Reaction with a Base:**
  - Ethanoic acid reacts with bases like sodium hydroxide to form a salt (sodium ethanoate/sodium acetate) and water.

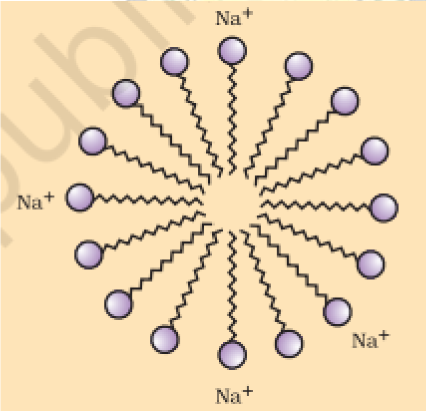
$$NaOH + CH_3COOH \rightarrow CH_3COONa + H_2O$$

- **Reaction with Carbonates and Hydrogencarbonates:**

- Ethanoic acid reacts with carbonates and hydrogencarbonates to produce a salt (sodium acetate), carbon dioxide, and water.

$$2CH_3COOH + Na_2CO_3 \rightarrow 2CH_3COONa + H_2O + CO_2$$
$$CH_3COOH + NaHCO_3 \rightarrow CH_3COONa + H_2O + CO_2$$

Soaps and Detergents



Formation of Micelles

- **Cleaning Action:** Soaps help clean oily dirt because they have both water-loving (hydrophilic) and oil-loving (hydrophobic) parts.
- **Soap Structure:**
  - Soaps are sodium or potassium salts of long-chain carboxylic acids.
  - The ionic end (sodium or potassium) is hydrophilic (attracted to water).
  - The carbon chain is hydrophobic (attracted to oil).
- **Micelles:**
  - When soap is in water with oil/dirt, the soap molecules form spherical structures called micelles.
  - In a micelle:
    - The hydrophobic carbon chains point inwards, trapping the oil/dirt.
    - The hydrophilic ionic ends point outwards, interacting with water.
- **Emulsion:** This creates an emulsion, where the oil/dirt is dispersed in the water and can be washed away.
- **Micelle in Hydrocarbon:** If you dissolve soap in a hydrocarbon (like oil), the micelle structure would be reversed:
  - The hydrophilic ionic ends would cluster in the center.
  - The hydrophobic carbon chains would extend outwards into the hydrocarbon.

ABHIGYAN ACADEMY

NDA CDS COACHING CENTRE