

Introduction to Carbon's Role and Bonding in Biological Molecules

Learning Objectives

By the end of this section, you will be able to:

- Explain why carbon is essential for life.
- Describe the function of functional groups in biological molecules.

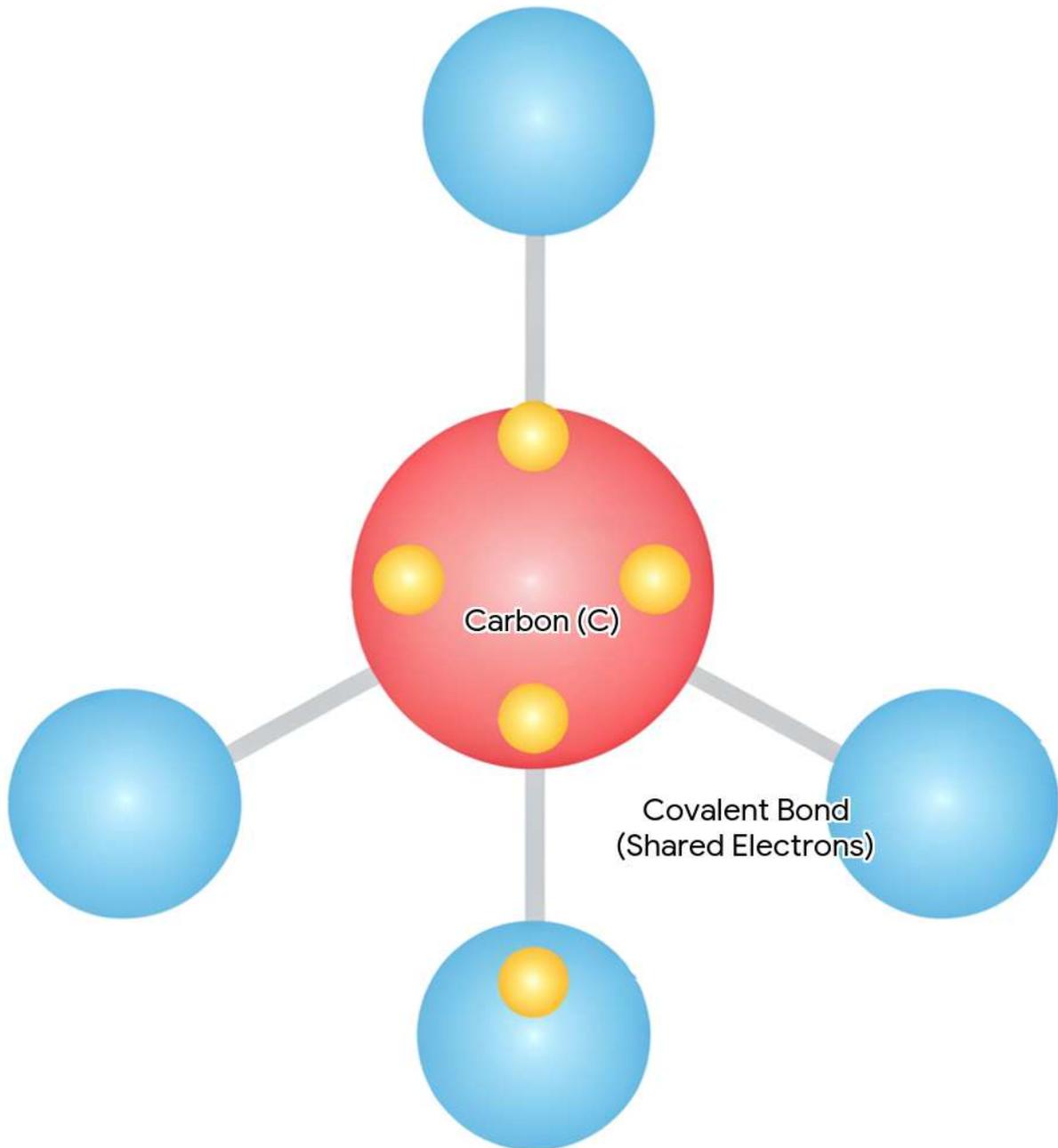
Cells are made up of many complex molecules called macromolecules, such as proteins, nucleic acids (like RNA and DNA), carbohydrates, and lipids. These macromolecules are a type of **organic molecule** (any substance, whether liquid, solid, or gas, that contains carbon) that are especially vital for life. Carbon is the foundational building block for all these macromolecules. Carbon Atom StructureThe carbon atom has special characteristics that allow it to form strong bonds with up to four different atoms. This makes it a highly flexible element, perfect for serving as the main structural component, or "backbone," of macromolecules.

Carbon Atom StructureIndividual carbon atoms do not have a full outermost electron shell. With an atomic number of 6 (meaning six electrons and six protons), the first two electrons occupy the inner shell, leaving four electrons in the second shell. To satisfy the octet rule (which states that atoms tend to form bonds so they have eight electrons in their outermost shell), carbon atoms can form up to four covalent bonds with other atoms. Methane (CH₄) is a good example: each of its four hydrogen atoms forms a single covalent bond with the carbon atom by sharing a pair of electrons. This process fills carbon's outermost electron shell.

Core ideas illustrated by AI

Carbon atoms have four electrons in their outermost shell and need eight to be stable (octet rule). To achieve this, carbon forms up to four covalent bonds with other atoms, sharing electrons. For example, in methane (CH₄), the central carbon atom forms a single covalent bond with each of its four hydrogen atoms, filling its outer shell and resulting in a tetrahedral shape.

Methane (CH₄) Covalent Bonding



Hydrogen (H)

Take a quiz to check your understanding

Question 1: What is the atomic number of carbon, and how are its electrons distributed in its shells?

- A. Atomic number 6; four electrons in the inner shell and two in the outer shell.
- B. Atomic number 6; two electrons in the inner shell and four in the outer shell.
- C. Atomic number 12; six electrons in the inner shell and six in the outer shell.
- D. Atomic number 4; two electrons in the inner shell and two in the outer shell.

Hydrocarbons: Definition, Energy, and Basic Structures

Hydrocarbons

Hydrocarbons are organic molecules made entirely of carbon and hydrogen, like the methane (CH₄) mentioned above. We find hydrocarbons in many artist materials—for instance, the turpentine used to thin oil paints or the mineral spirits for cleaning brushes. The numerous covalent bonds between atoms in hydrocarbons store a large amount of energy, which is released when these molecules burn (oxidize). Methane, an excellent fuel, is the simplest hydrocarbon molecule, featuring a central carbon atom bonded to four different hydrogen atoms, as shown in Figure 2.21. The specific shape of its electron orbitals determines the three-dimensional arrangement of the methane molecule. The carbon and its four hydrogen atoms form a tetrahedron, which has four triangular faces. Because of this, we describe methane as having a tetrahedral geometry.

Figure 2.21 Methane has a tetrahedral geometry, with each of the four hydrogen atoms spaced 109.5° apart.

Hydrocarbon ChainsAs the main structure of large molecules found in living organisms, hydrocarbons can exist as straight chains of carbon, rings of carbon, or combinations of both. Furthermore, the bonds between individual carbon atoms can be single, double, or triple covalent bonds, and each type of bond influences the molecule's shape in a particular way. This three-dimensional shape, or conformation, of these large molecules (macromolecules) is crucial to how they function.

Take a quiz to check your understanding

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Question 1: According to the source material, what is the primary factor that influences the three-dimensional shape or conformation of hydrocarbon molecules?

- A. The number of hydrogen atoms present.
- B. The type of covalent bonds (single, double, or triple)
- C. The presence of hydrocarbons in artist materials like turpentine.
- D. The overall length of the carbon chain.

Hydrocarbon Chains: Types and Geometries

Hydrocarbon Chains

Hydrocarbon Chains Hydrocarbon chains are formed by a series of bonds between carbon atoms. These chains can be branched or unbranched. Additionally, the different shapes created by single, double, and triple covalent bonds change the molecule's overall geometry, as Figure 2.22 demonstrates. Ethane, ethene, and ethyne are examples that show how different carbon-to-carbon bonds affect a molecule's shape. All three molecule names begin with the prefix "eth-," which indicates a two-carbon hydrocarbon. The suffixes "-ane," "-ene," and "-yne" refer to the presence of single, double, or triple carbon-carbon bonds, respectively.

Hydrocarbon Chains Following this pattern, propane, propene, and propyne are three-carbon molecules, while butane, butene, and butyne are four-carbon molecules, and so on. Double and triple bonds alter the molecule's geometry: single bonds allow rotation around the bond's axis, whereas double bonds result in a flat (planar) arrangement and triple bonds lead to a straight (linear) one. These specific geometries significantly impact the possible shapes a molecule can take.

Figure 2.22 When carbon forms single bonds with other atoms, the shape is tetrahedral. When two carbon atoms form a double bond, the shape is planar, or flat. Single bonds, like those in ethane, are able to rotate. Double bonds, like those in ethene, cannot rotate, so the atoms on either side are locked in place.

Take a quiz to check your understanding

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Question 1: Which of the following correctly describes the difference between ethene and ethyne?

- A. Ethene has a double carbon-carbon bond and a planar shape, while ethyne has a triple bond and a linear shape.

B. Ethene has a triple carbon-carbon bond and a linear shape, while ethyne has a double bond and a planar shape.

C. Ethene has a double carbon-carbon bond and a tetrahedral shape, while ethyne has a triple bond and a planar shape.

D. Ethene has a single carbon-carbon bond and a tetrahedral shape, while ethyne has a double bond and a planar shape.

Hydrocarbon Rings: Aliphatic and Aromatic Structures

Hydrocarbon Rings

Aliphatic Hydrocarbons The hydrocarbons discussed so far have been **aliphatic hydrocarbons**, which are characterized by linear chains of carbon atoms. Sometimes these can also form rings with only single bonds, as shown in Figure 2.23 with examples like cyclopentane and cyclohexane. **Aromatic Hydrocarbons** Another category, **aromatic hydrocarbons**, consists of closed rings of carbon atoms that have alternating single and double bonds. Aliphatic Hydrocarbons Ring structures are found in aliphatic hydrocarbons, containing only single bonds between carbons, such as the structure of cyclohexane (aliphatic), in contrast to a ring structure like benzene (aromatic) with its alternating single and double bonds in the ring, as depicted in Figure 2.23.

Aromatic Hydrocarbons Some biological molecules that incorporate the benzene ring include certain amino acids, cholesterol, and its related compounds, such as the hormones estrogen and testosterone. The benzene ring is also present in the herbicide 2,4-D. Benzene is naturally found in crude oil and has been identified as a carcinogen (a substance that can cause cancer). Some hydrocarbons contain both aliphatic and aromatic parts. Beta-carotene is an example of such a hydrocarbon.

Figure 2.23 Carbon can form five- and six-membered rings. Single or double bonds may connect the carbons in the ring, and nitrogen may be substituted for carbon.

Core ideas illustrated by AI

Take a quiz to check your understanding

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Question 1: Which of the following statements best defines an aliphatic hydrocarbon based on the provided text?

- A.** Hydrocarbons characterized by linear chains or rings of carbon atoms with only single bonds.
- B.** Hydrocarbons that are known to be carcinogens and are found in crude oil.
- C.** Hydrocarbons that always contain a benzene ring structure.
- D.** Hydrocarbons that consist of closed rings with alternating single and double bonds.