SECTION A: THE IMPORTANCE OF CARBON

1. Organic chemistry is the study of carbon compounds
2. Carbon atoms are the most versatile building blocks of molecules
3. Variation in carbon skeletons contributes the diversity of organic molecules
Introduction

• Although cells are 70-95% water, the rest consists mostly of carbon-based compounds.

• Proteins, DNA, carbohydrates, and other molecules that distinguish living matter from inorganic material are all composed of carbon atoms bonded to each other and to atoms of other elements.
  
  • These other elements commonly include hydrogen (H), oxygen (O), nitrogen (N), sulfur (S), and phosphorus (P).
1. Organic chemistry is the study of carbon compounds

- The study of carbon compounds, organic chemistry, focuses on any compound with carbon (organic compounds).
  - While the name, organic compounds, implies that these compounds can only come from biological processes, they can be synthesized by non-living reactions.
  - Organic compounds can range from the simple (CO₂ or CH₄) to complex molecules, like proteins, that may weigh over 100,000 daltons.
• The overall percentages of the major elements of life (C, H, O, N, S, and P) are quite uniform from one organism to another.

• However, because of carbon’s versatility, these few elements can be combined to build an inexhaustible variety of organic molecules.

• While the percentages of major elements do not differ within or among species, variations in organic molecules can distinguish even between individuals of a single species.
• The science of organic chemistry began in attempts to purify and improve the yield of products from other organisms.

• Later chemists learned to synthesize simple compounds in the laboratory, but they had no success with more complex compounds.

• The Swedish chemist Jons Jacob Berzelius was the first to make a distinction between organic compounds that seemed to arise only in living organisms and inorganic compounds from the nonliving world.

• This lead early organic chemists to propose *vitalism*, the belief in a life outside the limits of physical and chemical laws.
• Support for vitalism began to wane as organic chemists learned to synthesize more complex organic compounds in the laboratory.

• In the early 1800’s the German chemist Friedrich Wöhler and his students were able to synthesize urea from totally inorganic starting materials.

• In 1953, Stanley Miller at the University of Chicago was able to simulate chemical conditions on the primitive Earth to demonstrate the spontaneous synthesis of organic compounds.
• Organic chemists finally rejected vitalism and embraced *mechanism*.
  
  • Under mechanism, all natural phenomena, including the processes of life, are governed by the same physical and chemical laws.

• Organic chemistry was redefined as the study of carbon compounds regardless of origin.
  
  • Still, most organic compounds in an amazing diversity and complexity are produced by organisms.

  • However, the same rules apply to inorganic and organic compounds alike.
2. Carbon atoms are the most versatile building blocks of molecules

- With a total of 6 electrons, a carbon atom has 2 in the first shell and 4 in the second shell.
  - Carbon has little tendency to form ionic bonds by loosing or gaining 4 electrons.
  - Instead, carbon usually completes its valence shell by sharing electrons with other atoms in four covalent bonds.
  - This *tetravalence* by carbon makes large, complex molecules possible.
• When carbon forms covalent bonds with four other atoms, they are arranged at the corners of an imaginary tetrahedron with bond angles near $109^\circ$.
  • While drawn flat, they are actually three-dimensional.

• When two carbon atoms are joined by a double bond, all bonds around the carbons are in the same plane.
  • They have a flat, three-dimensional structure.
Fig. 4.2

(a) Methane

(b) Ethane

(c) Ethene (ethylene)
• The electron configuration of carbon gives it compatibility to form covalent bonds with many different elements.

• The valences of carbon and its partners can be viewed as the building code that governs the architecture of organic molecules.

Fig. 4.3
• In carbon dioxide, one carbon atom forms two double bonds with two different oxygen atoms.
  • The structural formula, $O = C = O$, shows that each atom has completed its valence shells.
  • While $CO_2$ can be classified at either organic or inorganic, its importance to the living world is clear.
    • $CO_2$ is the source for all organic molecules in organisms via the process of photosynthesis.
• Urea, $CO(NH_2)_2$, is another simple organic molecule in which each atom has enough covalent bonds to complete its valence shell.
3. Variation in carbon skeletons contributes to the diversity of organic molecules

- Carbon chains form the skeletons of most organic molecules.
  - The skeletons may vary in length and may be straight, branched, or arranged in closed rings.
  - The carbon skeletons may also include double bonds.
Fig. 4.4
• **Hydrocarbons** are organic molecules that consist of only carbon and hydrogen atoms.

  • Hydrocarbons are the major component of petroleum.

  • Petroleum is a fossil fuel because it consists of the partially decomposed remains of organisms that lived millions of years ago.

• Fats are biological molecules that have long hydrocarbon tails attached to a non-hydrocarbon component.

![Fat droplets (stained red)](image)

(a) A fat molecule

(b) Mammalian adipose cells

Fig. 4.5
• **Isomers** are compounds that have the same molecular formula but different structures and therefore different chemical properties.

• For example, butane and isobutane have the same molecular formula $\text{C}_4\text{H}_{10}$, but butane has a straight skeleton and isobutane has a branched skeleton.

• The two butanes are **structural isomers**, molecules with the same molecular formula but differ in the covalent arrangement of atoms.
• **Geometric isomers** are compounds with the same covalent partnerships that differ in their spatial arrangement around a carbon-carbon double bond.

• The double bond does not allow atoms to rotate freely around the bond axis.

• The biochemistry of vision involves a light-induced change in the structure of rhodopsin in the retina from one geometric isomer to another.

![Fig. 4.6b](b) Geometric isomers
• **Enantiomers** are molecules that are mirror images of each other
  
  • Enantiomers are possible if there are four different atoms or groups of atoms bonded to a carbon.
  
  • If this is true, it is possible to arrange the four groups in space in two different ways that are mirror images.
  
  • They are like left-handed and right-handed versions.
  
  • Usually one is biologically active, the other inactive.

(c) Enantiomers

Fig. 4.6c
• Even the subtle structural differences in two enantiomers have important functional significance because of emergent properties from the specific arrangements of atoms.

• One enantiomer of the drug thalidomide reduced morning sickness, its desired effect, but the other isomer caused severe birth defects.

• The L-Dopa isomer is an effective treatment of Parkinson’s disease, but the D-Dopa isomer is inactive.