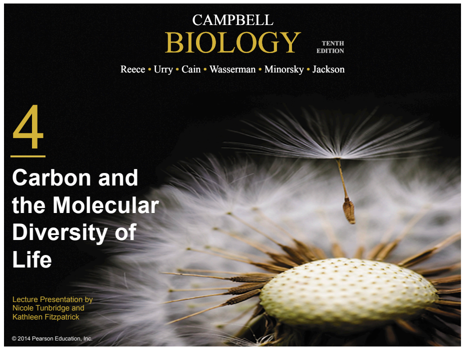
CAMPBELL
BIOLOGY TENTH EDITION

Reece • Urry • Cain • Wasserman • Minorsky • Jackson

4 Carbon and the Molecular Diversity of Life



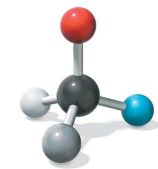
Lecture Presentation by
Nicole Tunbridge and
Kathleen Fitzpatrick

Carbon: The Backbone of Life

- Living organisms consist mostly of carbon-based compounds
- Carbon is unparalleled in its ability to form large, complex, and varied molecules
- Proteins, DNA, carbohydrates, and other molecules that distinguish living matter are all composed of carbon compounds

Figure 4.1

Figure 4.1a



Carbon can bond to four other atoms or groups of atoms, making a large variety of molecules possible.

Concept 4.1: Organic chemistry is the study of carbon compounds

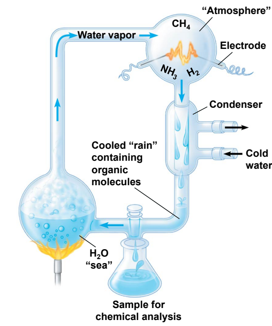
- **Organic chemistry** is the study of compounds that contain carbon
- Organic compounds range from simple molecules to colossal ones
- Most organic compounds contain hydrogen atoms in addition to carbon atoms

- Vitalism was the belief in a life force outside the jurisdiction of physical and chemical laws
- It was thought that organic compounds could only be produced in living organisms
- Vitalism was disproved when chemists were able to synthesize organic compounds

Organic Molecules and the Origin of Life on Earth

- Stanley Miller's classic experiment demonstrated the abiotic synthesis of organic compounds
- Experiments support the idea that abiotic synthesis of organic compounds, perhaps near volcanoes, could have been a stage in the origin of life

Figure 4.2



- Pioneers of organic chemistry helped shift the mainstream of biological thought from vitalism to mechanism
- Mechanism is the view that physical and chemical laws govern all natural phenomena

Concept 4.2: Carbon atoms can form diverse molecules by bonding to four other atoms

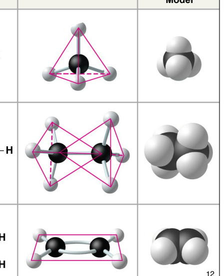
- Electron configuration is the key to an atom's characteristics
- Electron configuration determines the kinds and number of bonds an atom will form with other atoms

The Formation of Bonds with Carbon

- With four valence electrons, carbon can form four covalent bonds with a variety of atoms
- This ability makes large, complex molecules possible
- In molecules with multiple carbons, each carbon bonded to four other atoms has a tetrahedral shape
- However, when two carbon atoms are joined by a double bond, the atoms joined to the carbons are in the same plane as the carbons

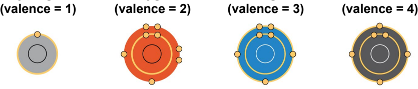
Figure 4.3

Molecule	Molecular Formula	Structural Formula	Ball-and-Stick Model	Space-Filling Model
(a) Methane	CH_4	H–C(H)(H)–H		
(b) Ethane	C_2H_6	H–C(H)(H)–C(H)(H)–H		
(c) Ethene (ethylene)	C_2H_4	$H_2C{=}CH_2$		



- The electron configuration of carbon gives it covalent compatibility with many different elements
- The valences of carbon and its most frequent partners (hydrogen, oxygen, and nitrogen) are the building code for the architecture of living molecules

Figure 4.4

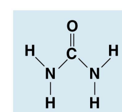


- Carbon atoms can partner with atoms other than hydrogen; for example:
  - Carbon dioxide: CO_2

$$O{=}C{=}O$$

  - Urea: $CO(NH_2)_2$

Figure 4.UN02

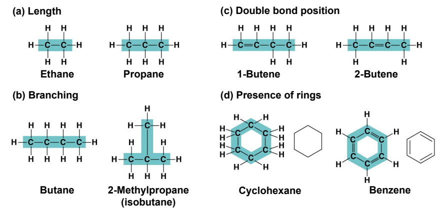


Urea

Molecular Diversity Arising from Variation in Carbon Skeletons

- Carbon chains form the skeletons of most organic molecules
- Carbon chains vary in length and shape

Figure 4.5



Animation: Carbon Skeletons

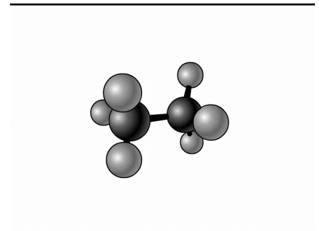


Figure 4.5a

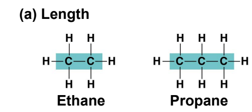


Figure 4.5b

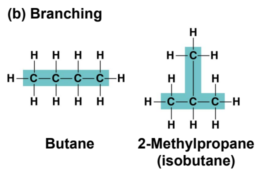


Figure 4.5c

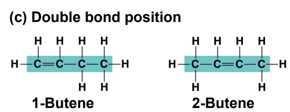
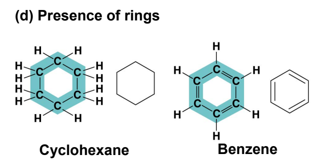


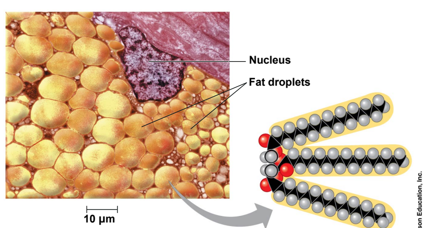
Figure 4.5d



Hydrocarbons

- **Hydrocarbons** are organic molecules consisting of only carbon and hydrogen
- Many organic molecules, such as fats, have hydrocarbon components
- Hydrocarbons can undergo reactions that release a large amount of energy

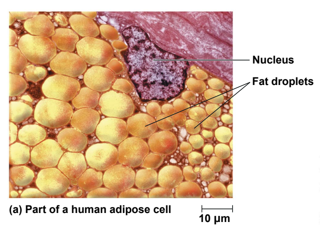
Figure 4.6



(a) Part of a human adipose cell

(b) A fat molecule

Figure 4.6a

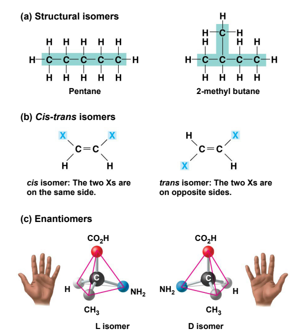


(a) Part of a human adipose cell

Isomers

- **Isomers** are compounds with the same molecular formula but different structures and properties
  - **Structural isomers** have different covalent arrangements of their atoms
  - ***Cis-trans* isomers** have the same covalent bonds but differ in spatial arrangements
  - **Enantiomers** are isomers that are mirror images of each other

Figure 4.7



Animation: Isomers

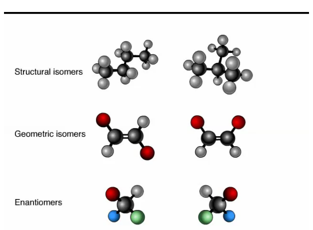


Figure 4.7a

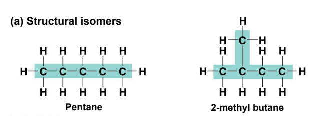


Figure 4.7b

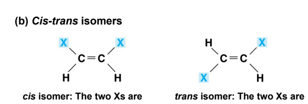
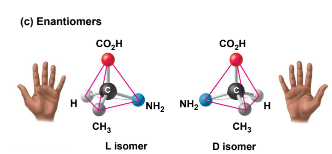


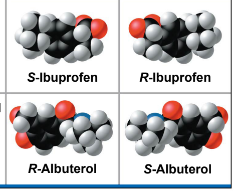
Figure 4.7c



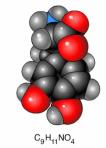
- Enantiomers are important in the pharmaceutical industry
- Two enantiomers of a drug may have different effects
- Usually only one isomer is biologically active
- Differing effects of enantiomers demonstrate that organisms are sensitive to even subtle variations in molecules

Figure 4.8

Drug	Effects	Effective Enantiomer	Ineffective Enantiomer
Ibuprofen	Reduces inflammation and pain	*S*-Ibuprofen	*R*-Ibuprofen
Albuterol	Relaxes bronchial (airway) muscles, improving airflow in asthma patients	*R*-Albuterol	*S*-Albuterol



Animation: L-Dopa



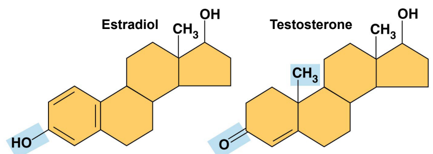
Concept 4.3: A few chemical groups are key to molecular function

- Distinctive properties of organic molecules depend on the carbon skeleton and on the chemical groups attached to it
- A number of characteristic groups can replace the hydrogens attached to skeletons of organic molecules

The Chemical Groups Most Important in the Processes of Life

- Estradiol and testosterone are both steroids with a common carbon skeleton, in the form of four fused rings
- These sex hormones differ only in the chemical groups attached to the rings of the carbon skeleton

Figure 4.UN03



- **Functional groups** are the components of organic molecules that are most commonly involved in chemical reactions
- The number and arrangement of functional groups give each molecule its unique properties

- The seven functional groups that are most important in the chemistry of life
  - Hydroxyl group
  - Carbonyl group
  - Carboxyl group
  - Amino group
  - Sulfhydryl group
  - Phosphate group
  - Methyl group

Figure 4.9

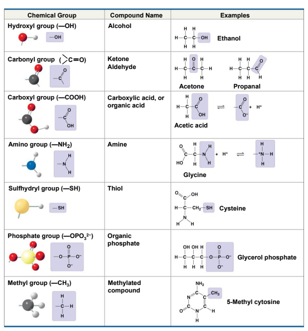


Figure 4.9a

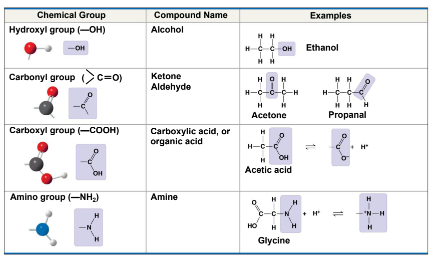


Figure 4.9aa

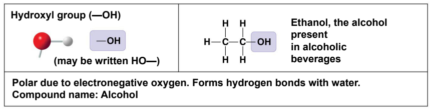


Figure 4.9ab

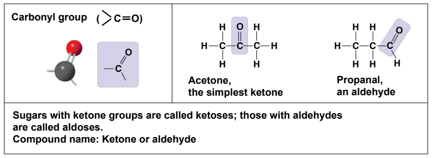


Figure 4.9ac

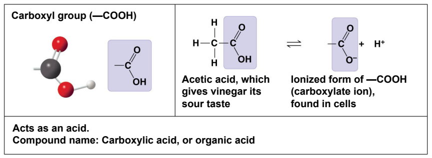


Figure 4.9ad

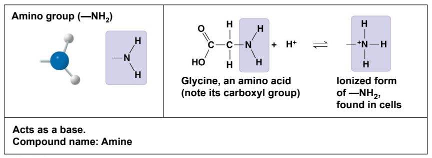


Figure 4.9b

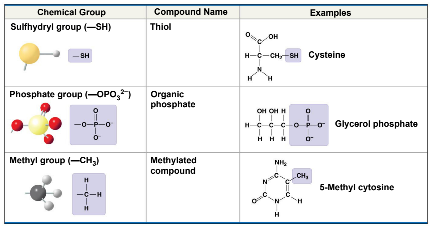


Figure 4.9ba

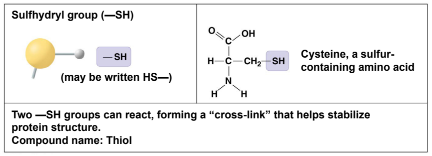


Figure 4.9bb

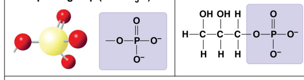
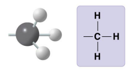
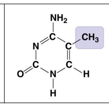
Phosphate group (—OPO_3^{2-})	
	Glycerol phosphate, which takes part in many important chemical reactions in cells
Contributes negative charge. When attached, confers on a molecule the ability to react with water, releasing energy. Compound name: Organic phosphate	

Figure 4.9bc

Methyl group (—CH_3)	
	 5-Methyl cytosine, a component of DNA that has been modified by addition of a methyl group
Affects the expression of genes. Affects the shape and function of sex hormones. Compound name: Methylated compound	

ATP: An Important Source of Energy for Cellular Processes

- An important organic phosphate is **adenosine triphosphate** (ATP)
- ATP consists of an organic molecule called adenosine attached to a string of three phosphate groups
- ATP stores the potential to react with water, a reaction that releases energy to be used by the cell

Figure 4.UN04

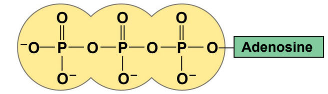
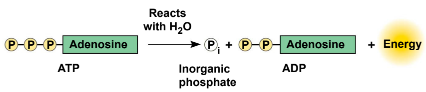


Figure 4.UN05



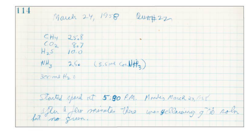
The Chemical Elements of Life: *A Review*

- The versatility of carbon makes possible the great diversity of organic molecules
- Variation at the molecular level lies at the foundation of all biological diversity

Figure 4.UN01a

Product Compound	Molecular Formula	Molar Ratio (Relative to Glycine)
Glycine	$C_2H_5NO_2$	1.0
Serine	$C_3H_7NO_3$	3.0×10^{-2}
Methionine	$C_5H_{11}NO_2S$	1.8×10^{-3}
Alanine	$C_3H_7NO_2$	1.1

Figure 4.UN01b



Some of Stanley Miller's notes from his 1958 hydrogen sulfide (H_2S) experiment

Figure 4.UN01c

Some of Stanley Miller's original vials from his 1958 hydrogen sulfide (H_2S) experiment

Figure 4.UN06

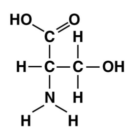


Figure 4.UN07

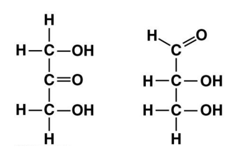


Figure 4.UN08

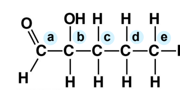
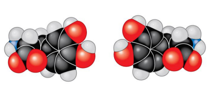


Figure 4.UN09



L-dopa D-dopa

Figure 4.UN10