LECTURE PRESENTATIONS

For CAMPBELL BIOLOGY, NINTH EDITION

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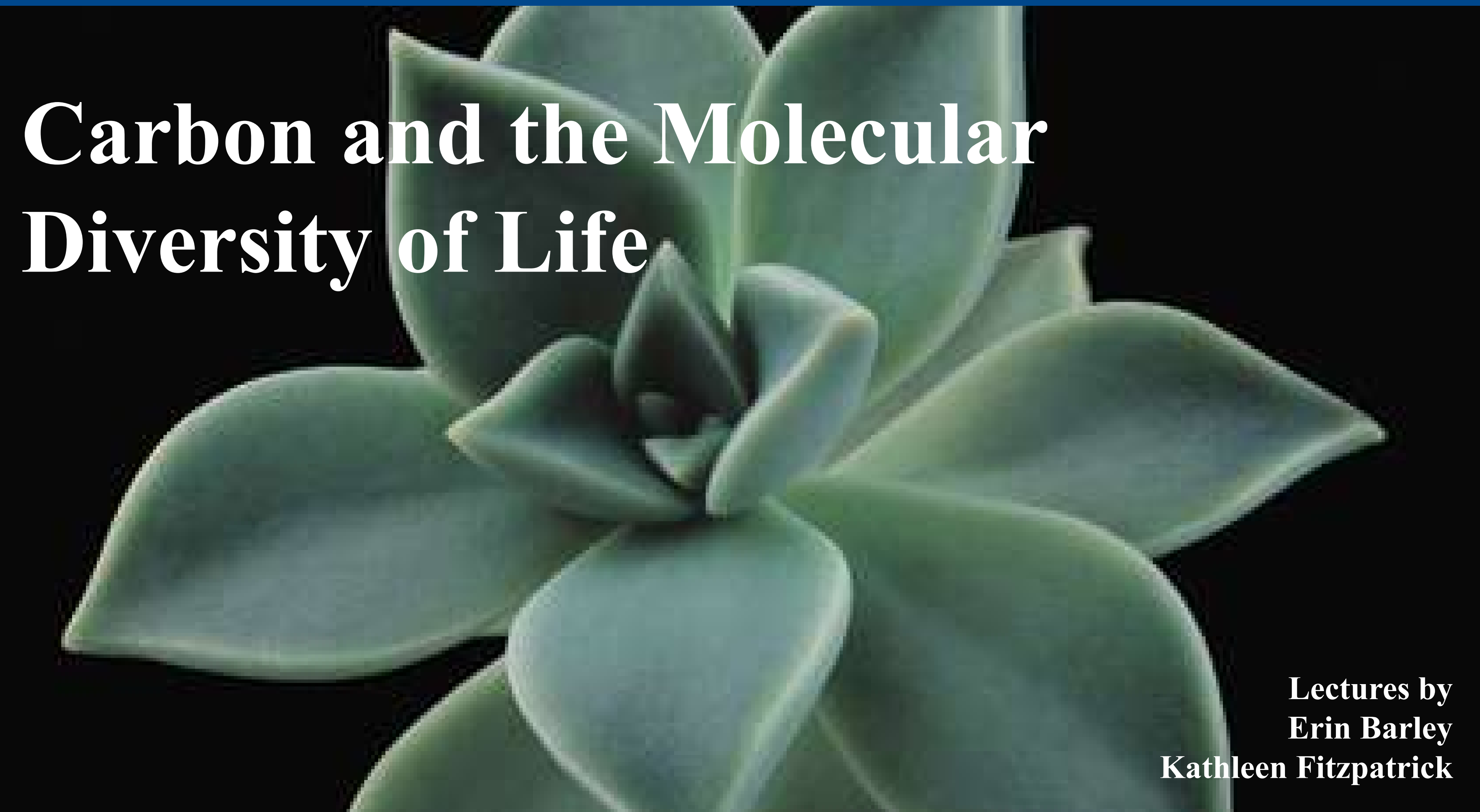
Chapter 4

Carbon and the Molecular Diversity of Life



Lectures by
Erin Barley
Kathleen Fitzpatrick

Overview: Carbon: The Backbone of Life

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

Figure 4.1

Concept 4.1: Organic chemistry is the study of carbon compounds

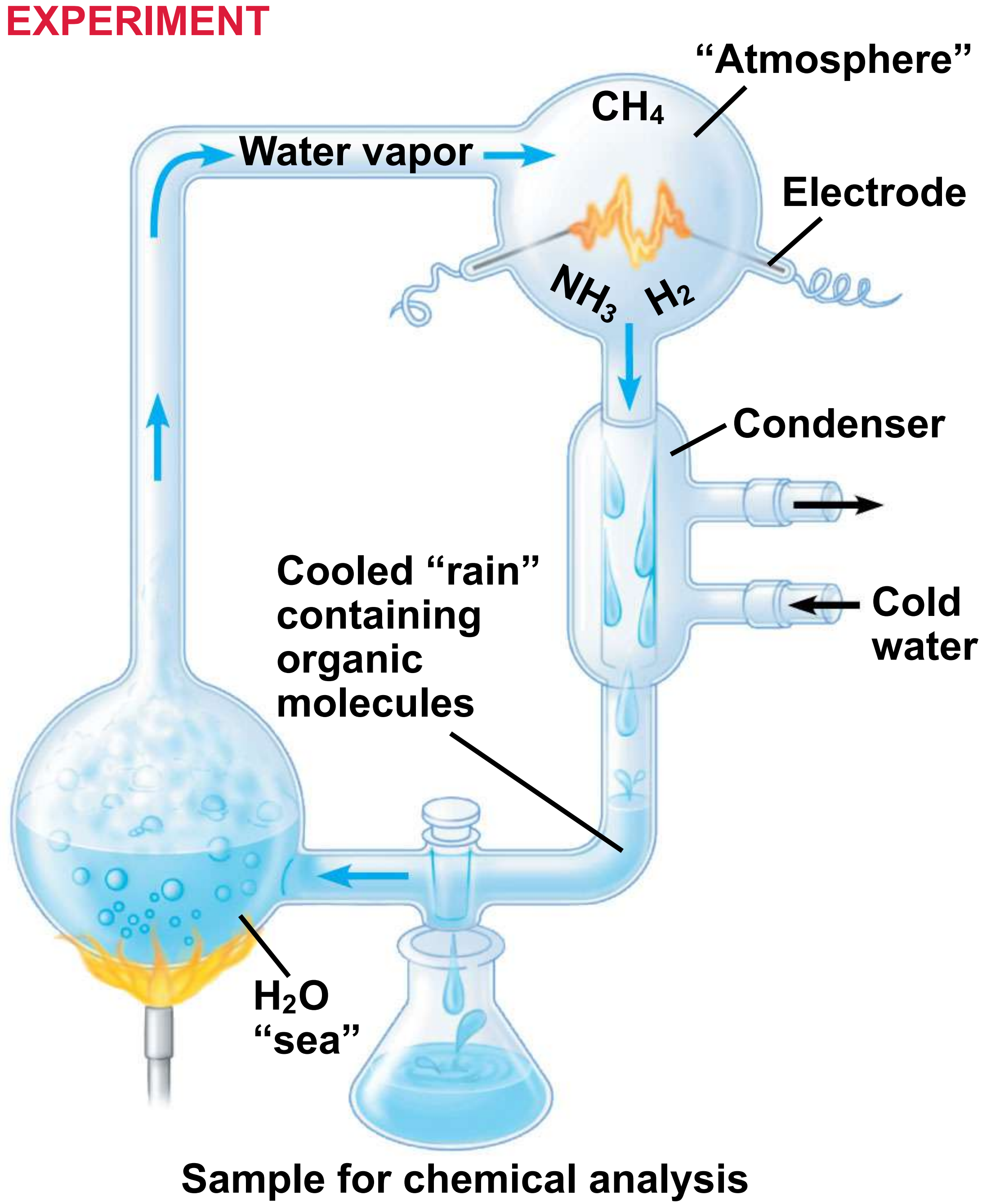
- **Organic chemistry** is the study of compounds that contain carbon
- Organic compounds range from simple molecules to colossal ones
- Most organic compounds contain hydrogen atoms in addition to carbon atoms

- *Vitalism*, the idea that organic compounds arise only in organisms, was disproved when chemists synthesized these compounds
- *Mechanism* is the view that all natural phenomena are governed by physical and chemical laws

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


EXPERIMENT
"Atmosphere"
CH_4
Water vapor
Electrode
NH_3
H_2
Condenser
Cooled "rain" containing organic molecules
Cold water
H_2O "sea"
Sample for chemical analysis

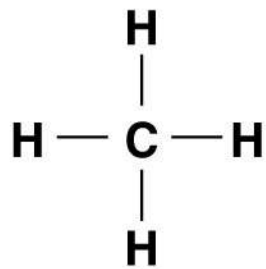
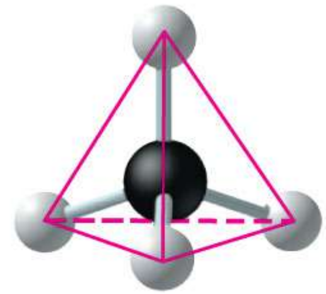
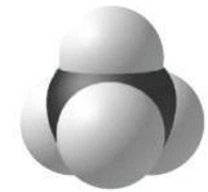
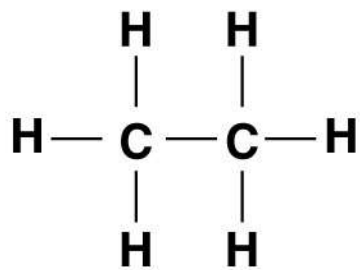
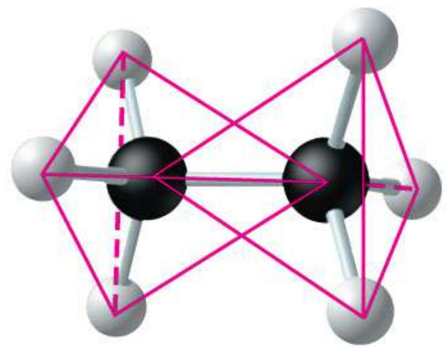
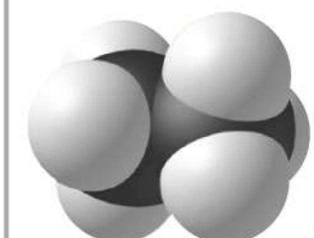
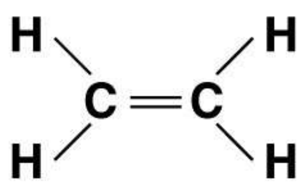
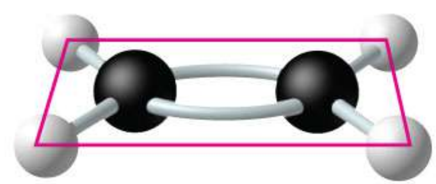
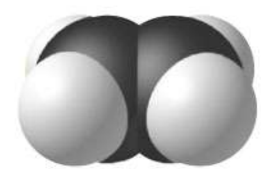
Concept 4.2: Carbon atoms can form diverse molecules by bonding to four other atoms

- 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

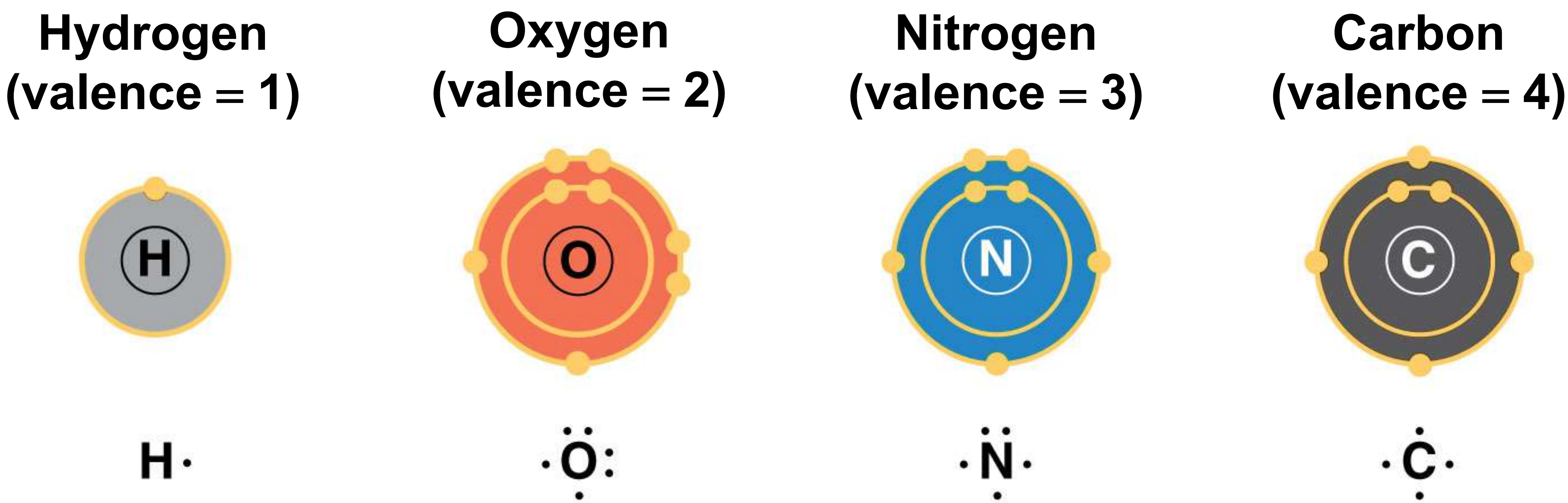
- With four valence electrons, carbon can form four covalent bonds with a variety of atoms
- This ability makes large, complex molecules possible
- In molecules with multiple carbons, each carbon bonded to four other atoms has a tetrahedral shape
- However, when two carbon atoms are joined by a double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

Figure 4.3

Name and Comment	Molecular Formula	Structural Formula	Ball-and-Stick Model	Space-Filling Model
(a) Methane	CH_4			
(b) Ethane	C_2H_6			
(c) Ethene (ethylene)	C_2H_4			

- 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” that governs the architecture of living molecules

Figure 4.4

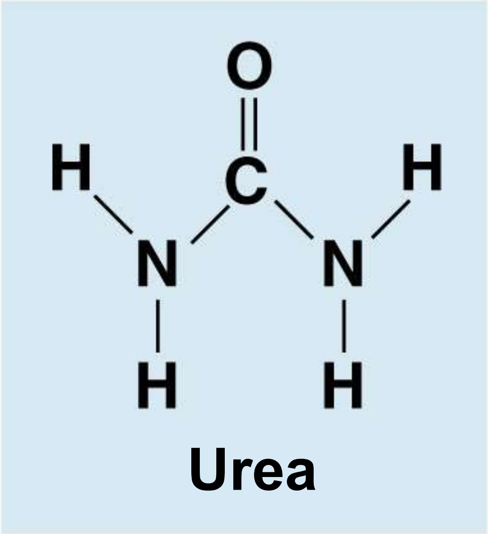


Hydrogen
(valence = 1)
Oxygen
(valence = 2)
Nitrogen
(valence = 3)
Carbon
(valence = 4)
H
O
N
C
H
O
N
C

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

  - Urea: $CO(NH_2)_2$

Figure 4.UN01

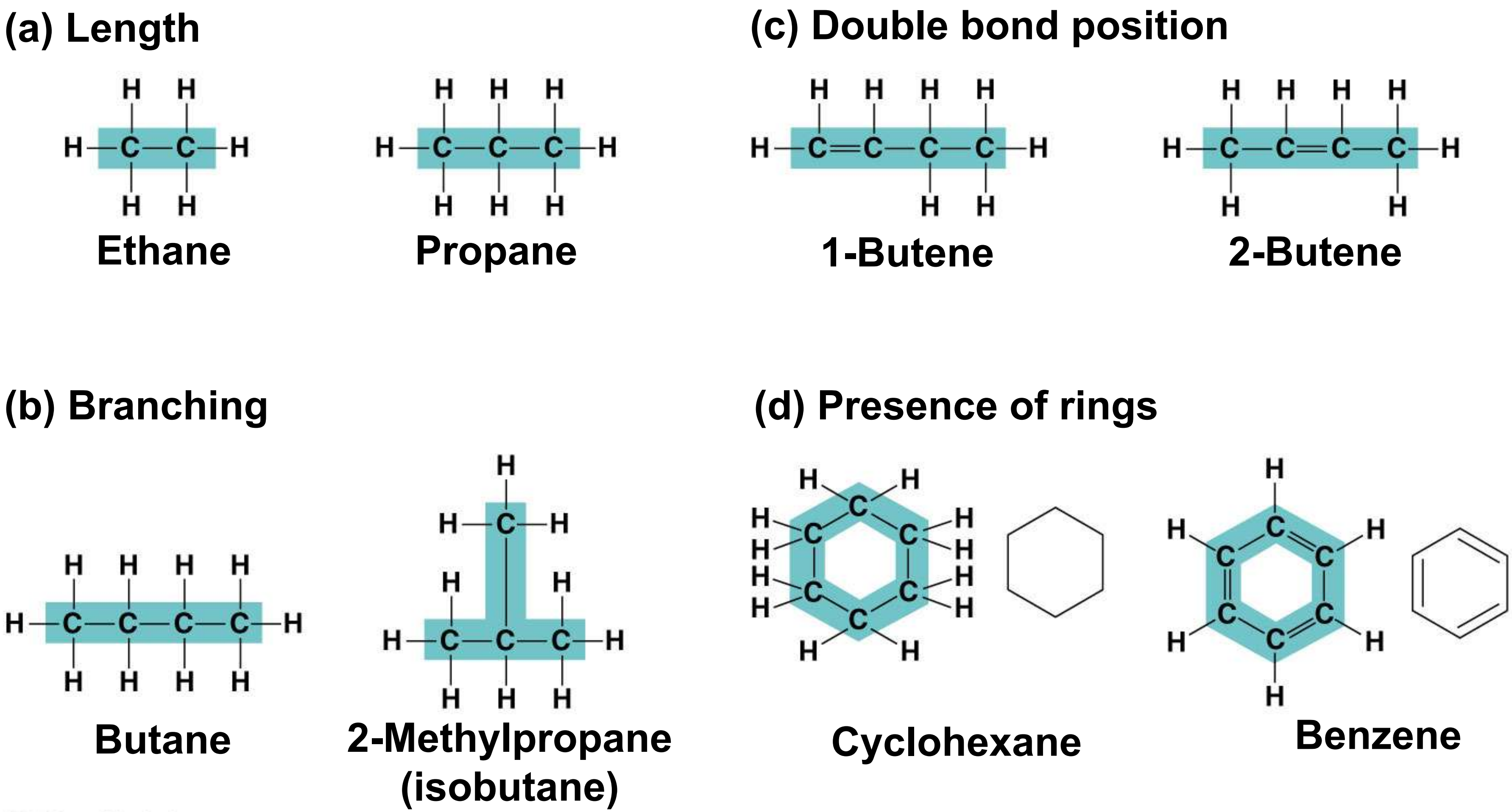


Molecular Diversity Arising from Carbon Skeleton Variation

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

PLAY Animation: Carbon Skeletons

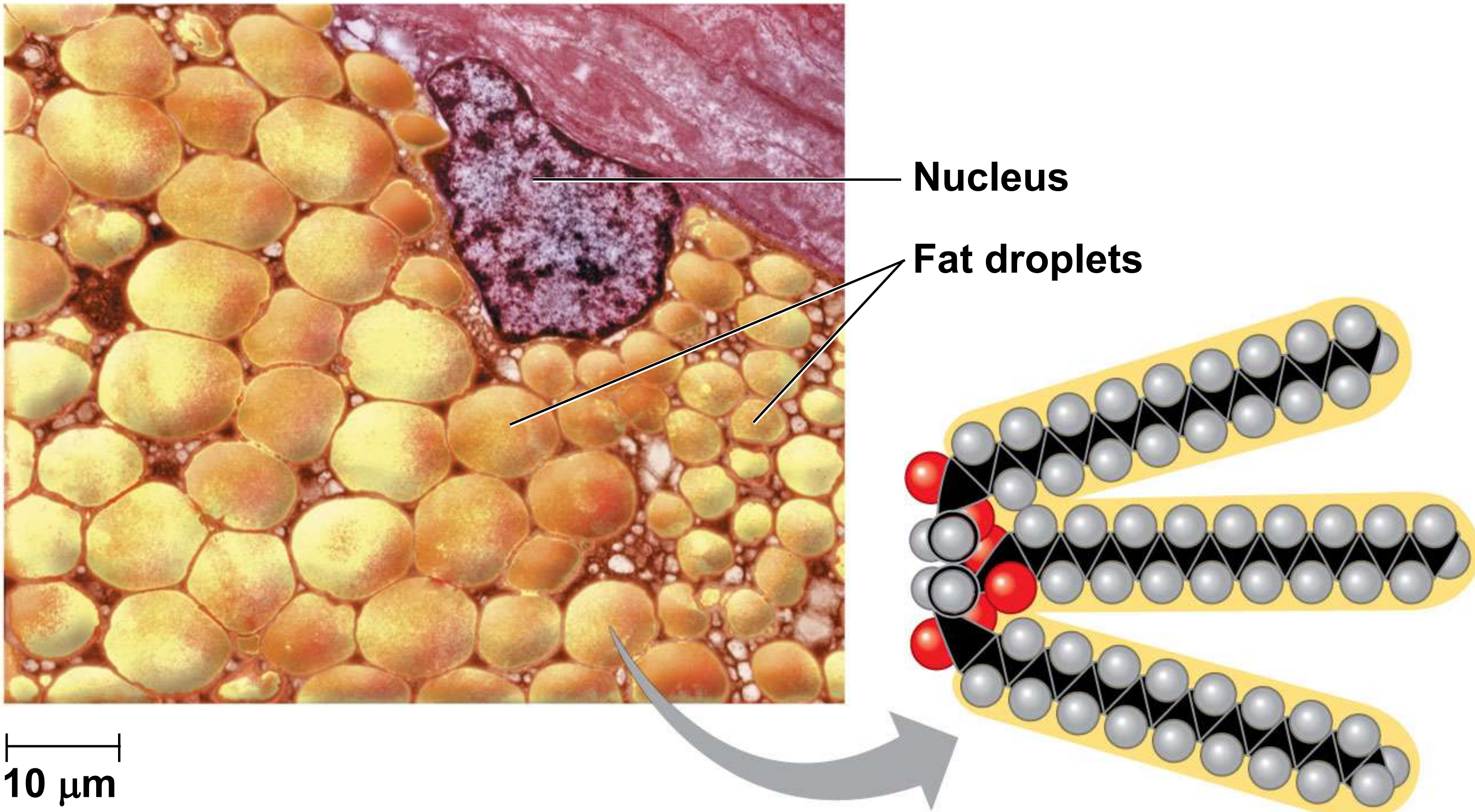
Figure 4.5


(a) Length
Ethane
Propane
(c) Double bond position
1-Butene
2-Butene
(b) Branching
Butane
2-Methylpropane
(isobutane)
(d) Presence of rings
Cyclohexane
Benzene

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**

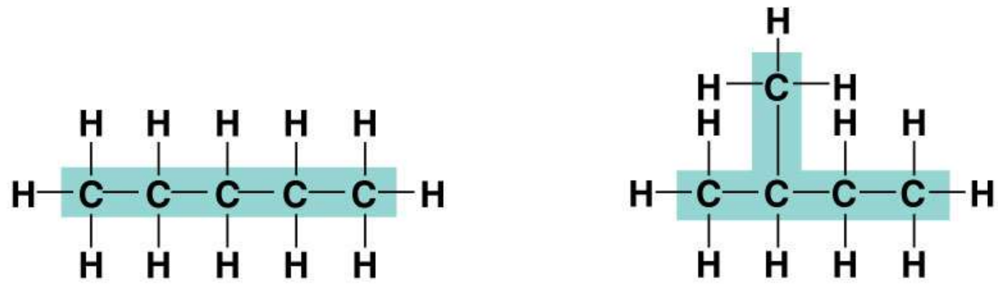
Isomers

- **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

PLAY Animation: Isomers

Figure 4.7

(a) Structural isomers

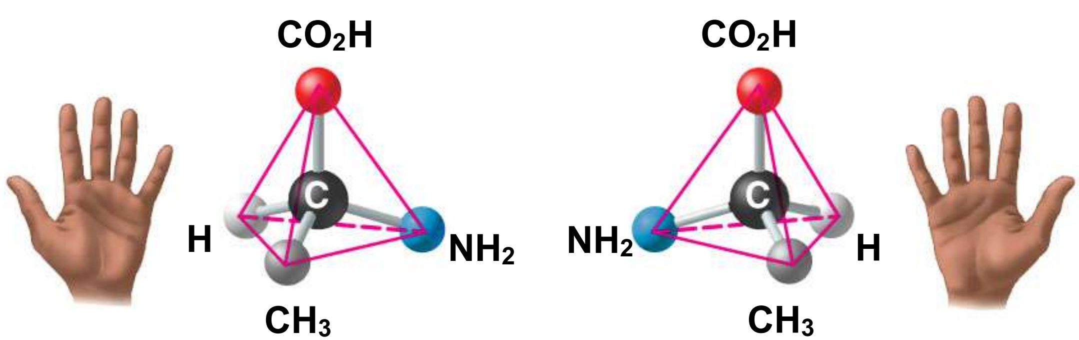


(b) *Cis-trans* isomers

cis isomer: The two Xs are on the same side.

trans isomer: The two Xs are on opposite sides.

(c) Enantiomers



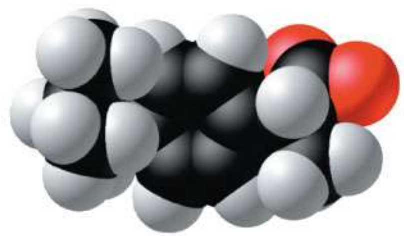
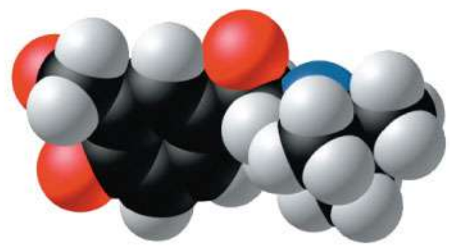
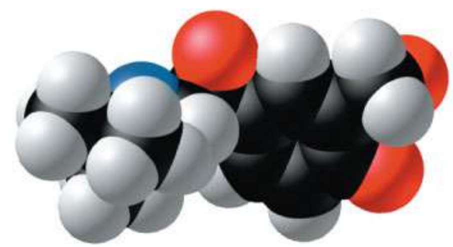
L isomer

D isomer

- 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

PLAY Animation: L-Dopa

Figure 4.8

Drug	Condition	Effective Enantiomer	Ineffective Enantiomer
Ibuprofen	Pain; inflammation	 *S*-Ibuprofen	 *R*-Ibuprofen
Albuterol	Asthma	 *R*-Albuterol	 *S*-Albuterol

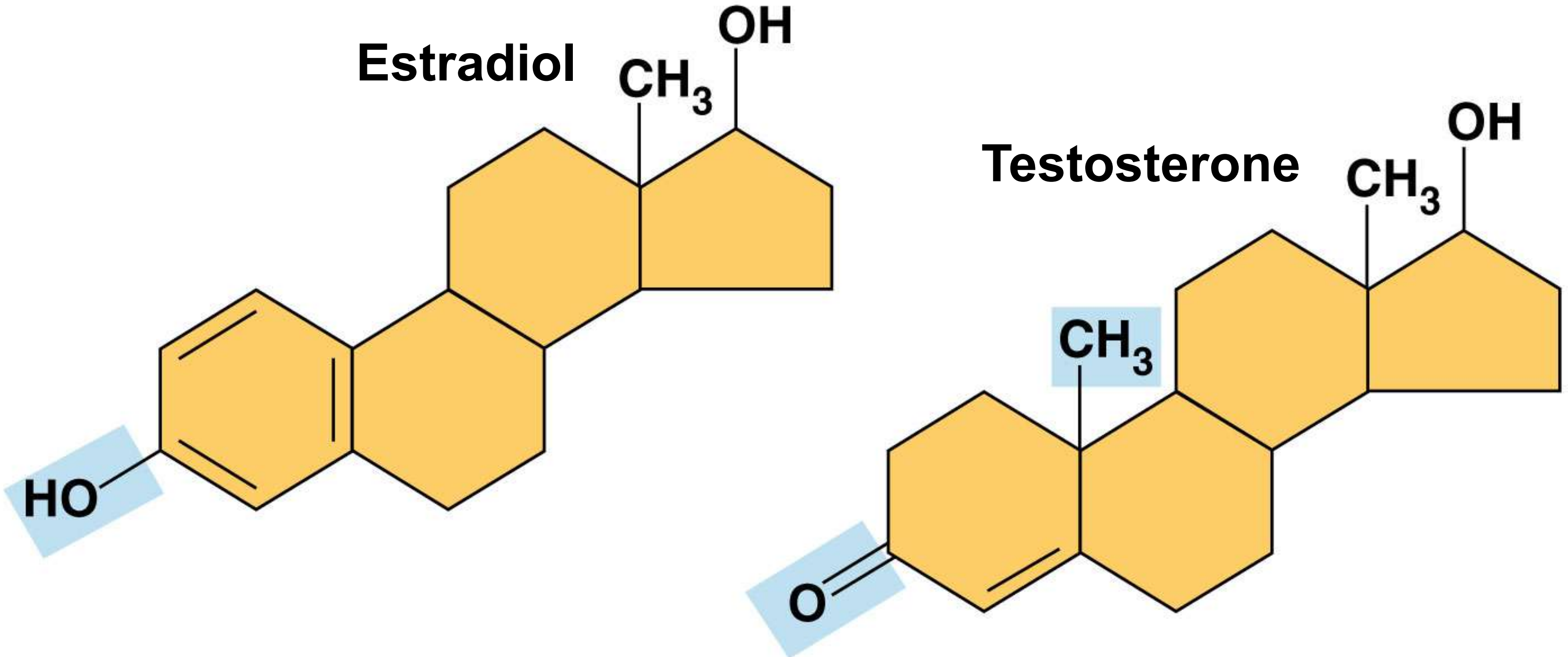
Concept 4.3: A few chemical groups are key to the functioning of biological molecules

- Distinctive properties of organic molecules depend on the carbon skeleton and on the molecular components 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

- **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

Figure 4.UN02



- 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-a

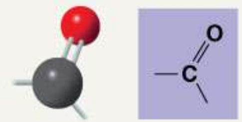
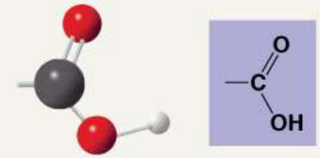
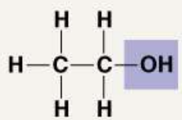
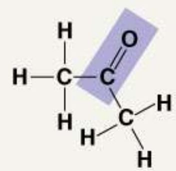
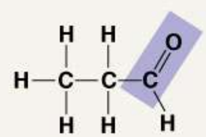
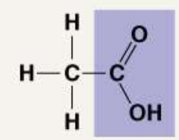
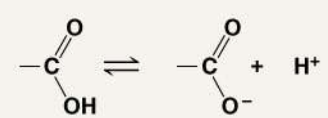
CHEMICAL GROUP	Hydroxyl	Carbonyl	Carboxyl
STRUCTURE	 (may be written HO—)		
NAME OF COMPOUND	Alcohols (Their specific names usually end in *-ol.)*	Ketones if the carbonyl group is within a carbon skeleton Aldehydes if the carbonyl group is at the end of the carbon skeleton	Carboxylic acids, or organic acids
EXAMPLE	 Ethanol	 Acetone  Propanal	 Acetic acid
FUNCTIONAL PROPERTIES	• Is polar as a result of the electrons spending more time near the electronegative oxygen atom. • Can form hydrogen bonds with water molecules, helping dissolve organic compounds such as sugars.	• A ketone and an aldehyde may be structural isomers with different properties, as is the case for acetone and propanal. • Ketone and aldehyde groups are also found in sugars, giving rise to two major groups of sugars: ketoses (containing ketone groups) and aldoses (containing aldehyde groups).	• Acts as an acid; can donate an H^+ because the covalent bond between oxygen and hydrogen is so polar:  Nonionized Ionized • Found in cells in the ionized form with a charge of 1– and called a carboxylate ion.

Figure 4.9-b

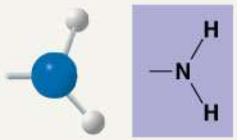
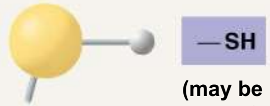
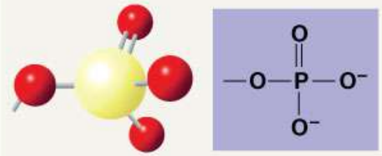
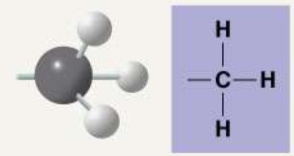
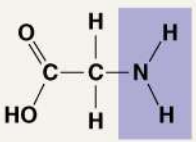
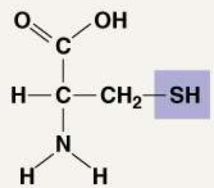
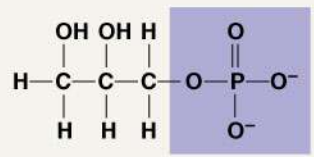
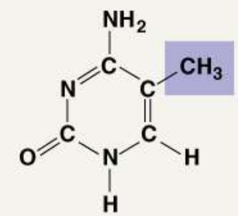
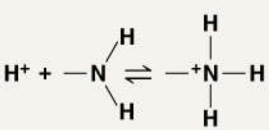
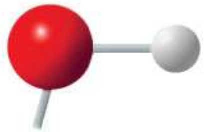
Amino	Sulfhydryl	Phosphate	Methyl
 	 (may be written HS—)	 	
Amines	Thiols	Organic phosphates	Methylated compounds
 Glycine	 Cysteine	 Glycerol phosphate	 5-Methyl cytidine
• Acts as a base; can pick up an H^+ from the surrounding solution (water, in living organisms):  Nonionized Ionized • Found in cells in the ionized form with a charge of 1+.	• Two sulfhydryl groups can react, forming a covalent bond. This "cross-linking" helps stabilize protein structure. • Cross-linking of cysteines in hair proteins maintains the curliness or straightness of hair. Straight hair can be "permanently" curled by shaping it around curlers and then breaking and re-forming the cross-linking bonds.	• Contributes negative charge to the molecule of which it is a part (2– when at the end of a molecule, as above; 1– when located internally in a chain of phosphates). • Molecules containing phosphate groups have the potential to react with water, releasing energy.	• Addition of a methyl group to DNA, or to molecules bound to DNA, affects the expression of genes. • Arrangement of methyl groups in male and female sex hormones affects their shape and function.

Figure 4.9a

Hydroxyl

STRUCTURE



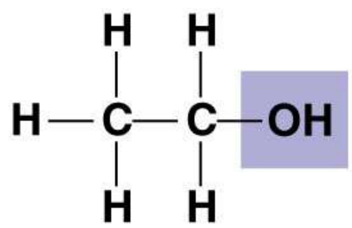
—OH

(may be written HO—)

NAME OF COMPOUND

Alcohols (Their specific names usually end in *-ol*.)

EXAMPLE



Ethanol

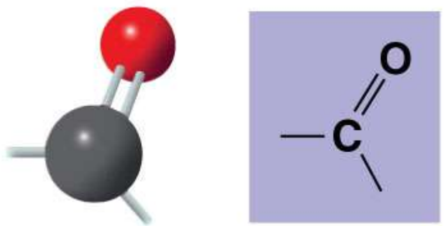
FUNCTIONAL PROPERTIES

- **Is polar as a result of the electrons spending more time near the electronegative oxygen atom.**
- **Can form hydrogen bonds with water molecules, helping dissolve organic compounds such as sugars.**

Figure 4.9b

Carbonyl

STRUCTURE

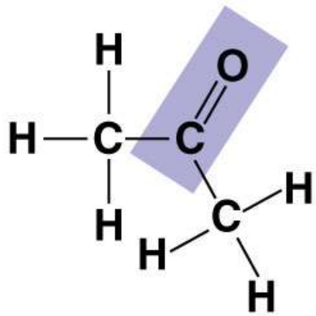


Ketones if the carbonyl group is within a carbon skeleton

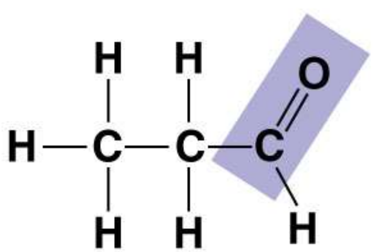
Aldehydes if the carbonyl group is at the end of the carbon skeleton

NAME OF COMPOUND

EXAMPLE



Acetone



Propanal

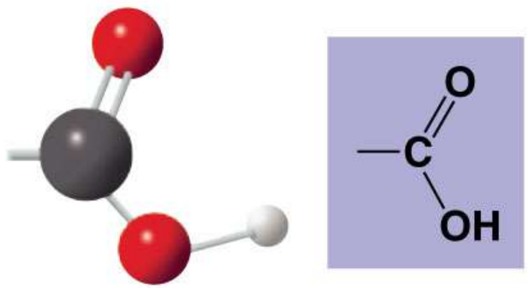
- A ketone and an aldehyde may be structural isomers with different properties, as is the case for acetone and propanal.
- Ketone and aldehyde groups are also found in sugars, giving rise to two major groups of sugars: ketoses (containing ketone groups) and aldoses (containing aldehyde groups).

FUNCTIONAL PROPERTIES

Figure 4.9c

Carboxyl

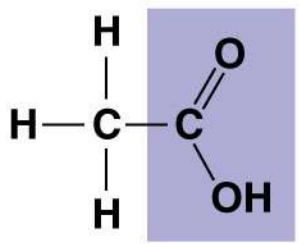
STRUCTURE



NAME OF COMPOUND

Carboxylic acids, or organic acids

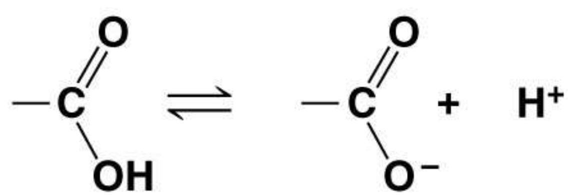
EXAMPLE



Acetic acid

FUNCTIONAL PROPERTIES

- Acts as an acid; can donate an H^+ because the covalent bond between oxygen and hydrogen is so polar:



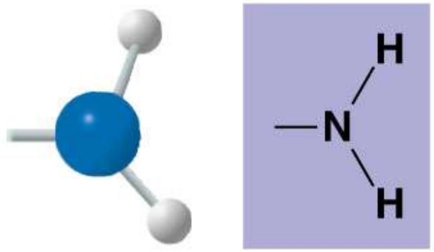
Nonionized Ionized

- Found in cells in the ionized form with a charge of 1– and called a carboxylate ion.

Figure 4.9d

Amino

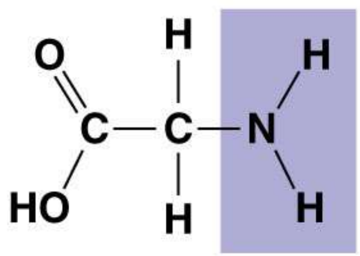
STRUCTURE



NAME OF COMPOUND

Amines

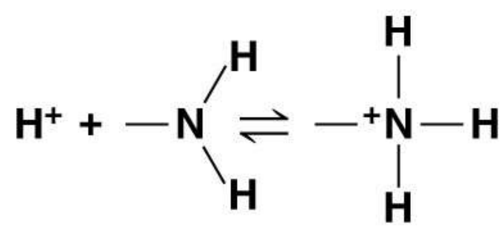
EXAMPLE



Glycine

FUNCTIONAL PROPERTIES

- Acts as a base; can pick up an H^+ from the surrounding solution (water, in living organisms):

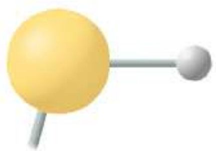


Nonionized Ionized

- Found in cells in the ionized form with a charge of 1+.

Sulfhydryl

STRUCTURE



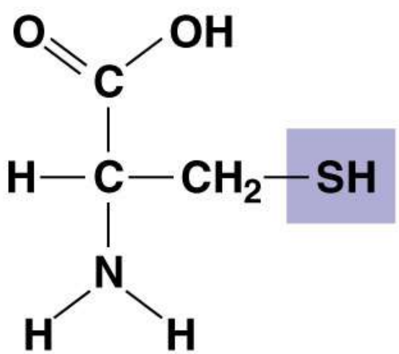
—SH

(may be written HS—)

NAME OF COMPOUND

Thiols

EXAMPLE



Cysteine

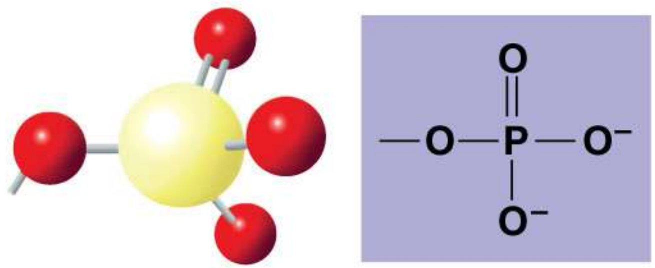
FUNCTIONAL PROPERTIES

- Two sulfhydryl groups can react, forming a covalent bond. This "cross-linking" helps stabilize protein structure.
- Cross-linking of cysteines in hair proteins maintains the curliness or straightness of hair. Straight hair can be "permanently" curled by shaping it around curlers and then breaking and re-forming the cross-linking bonds.

Figure 4.9f

Phosphate

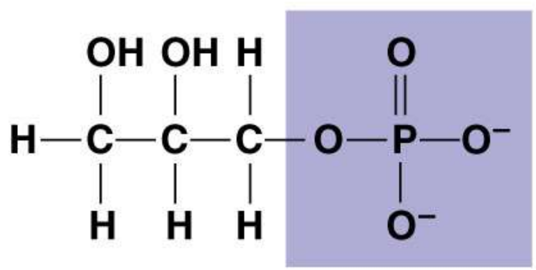
STRUCTURE



NAME OF COMPOUND

Organic phosphates

EXAMPLE



Glycerol phosphate

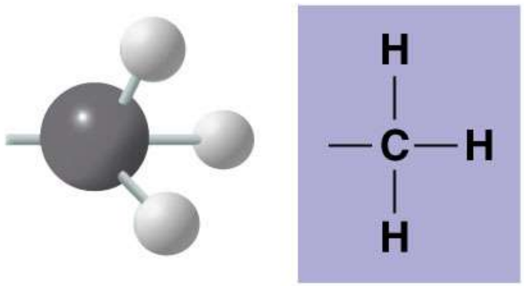
FUNCTIONAL PROPERTIES

- Contributes negative charge to the molecule of which it is a part (2– when at the end of a molecule, as at left; 1– when located internally in a chain of phosphates).
- Molecules containing phosphate groups have the potential to react with water, releasing energy.

Figure 4.9g

Methyl

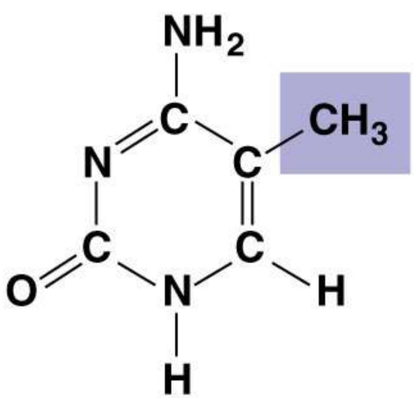
STRUCTURE



Methylated compounds

NAME OF COMPOUND

EXAMPLE



5-Methyl cytidine

FUNCTIONAL PROPERTIES

- **Addition of a methyl group to DNA, or to molecules bound to DNA, affects the expression of genes.**
- **Arrangement of methyl groups in male and female sex hormones affects their shape and function.**

ATP: An Important Source of Energy for Cellular Processes

- One phosphate molecule, **adenosine triphosphate** (**ATP**), is the primary energy-transferring molecule in the cell
- ATP consists of an organic molecule called adenosine attached to a string of three phosphate groups

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. UN05