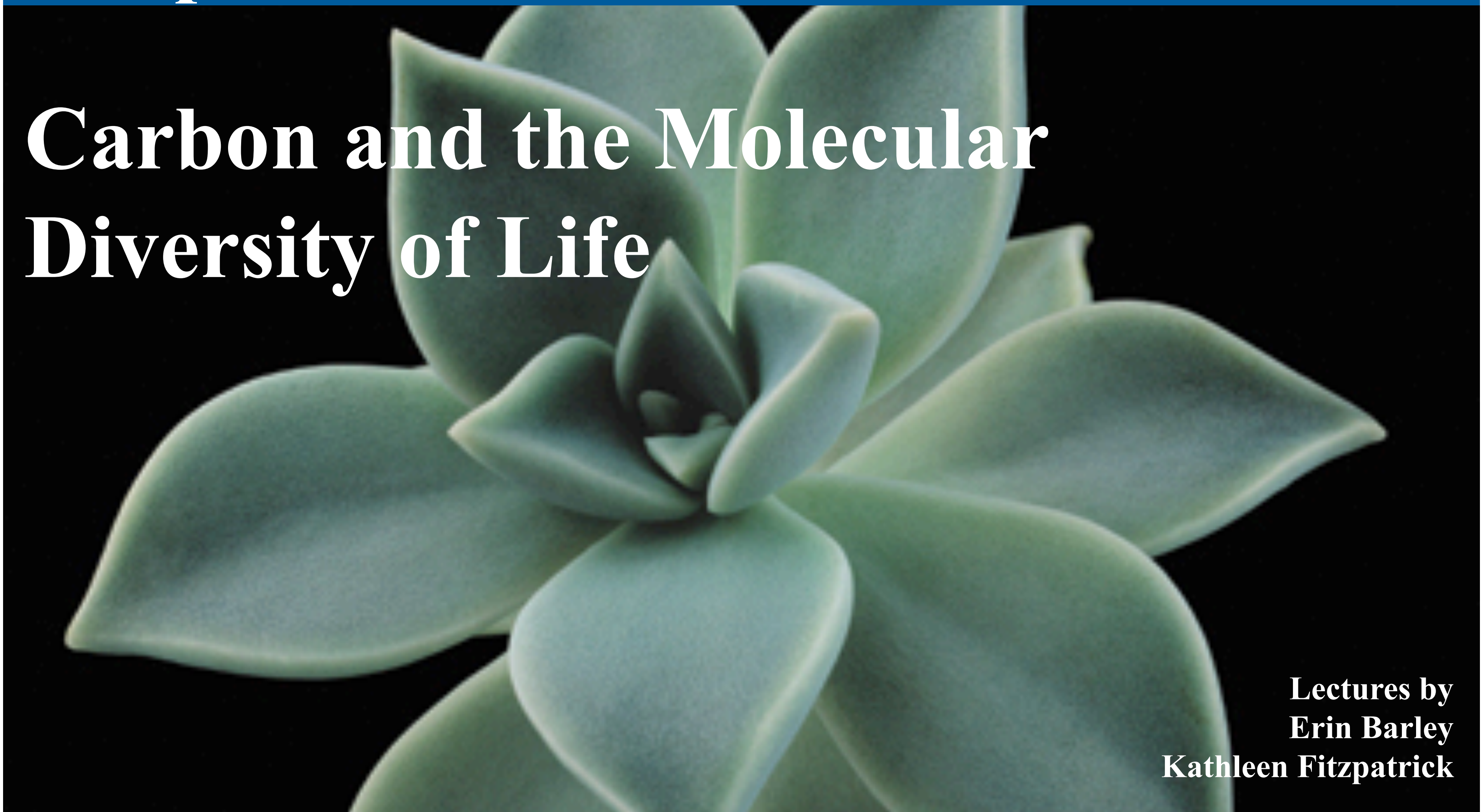
LECTURE PRESENTATIONS

For CAMPBELL BIOLOGY, NINTH EDITION

Jane B. Reece, Lisa A. Urry, Michael L. Cain, Steven A. Wasserman, Peter V. Minorsky, Robert B. Jackson

Chapter 4

Carbon and the Molecular Diversity of Life



Lectures by
Erin Barley
Kathleen Fitzpatrick

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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

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Figure 4.1

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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

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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

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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

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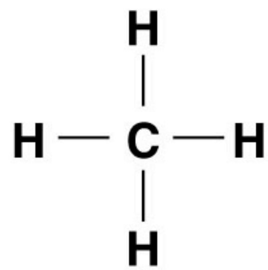
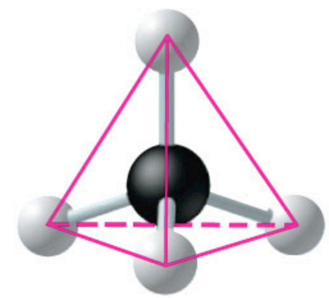
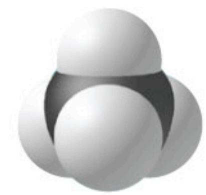
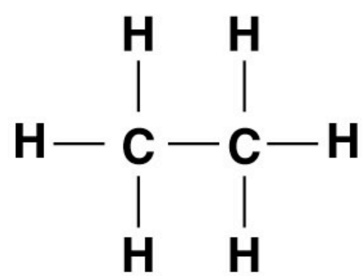
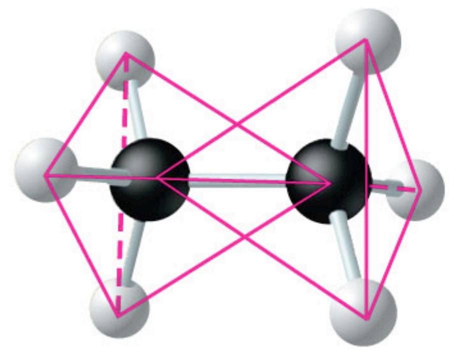
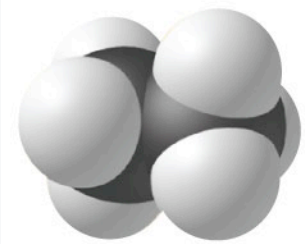
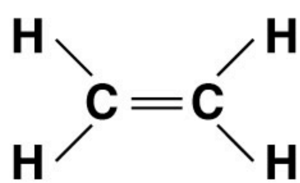
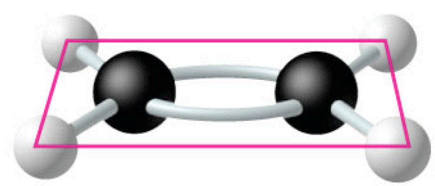
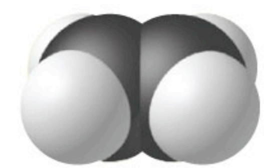
Figure 4.3

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			

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- 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

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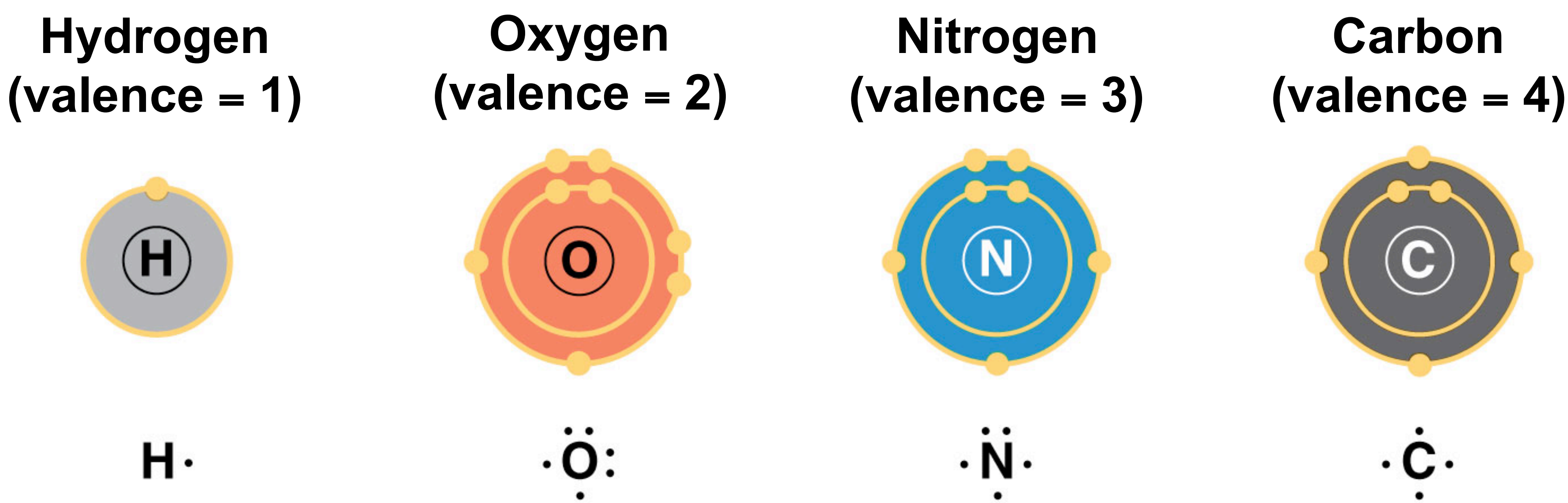
Figure 4.4



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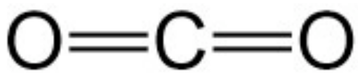
- Carbon atoms can partner with atoms other than hydrogen; for example:
  - Carbon dioxide: CO_2



  - Urea: $CO(NH_2)_2$

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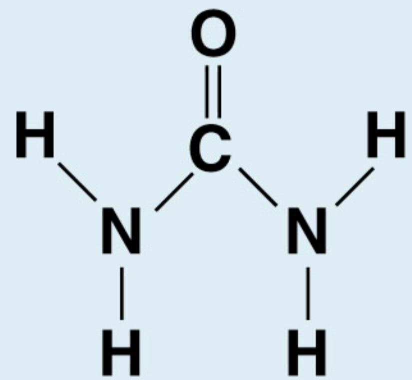
Figure 4.UN01



Urea

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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

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Figure 4.5

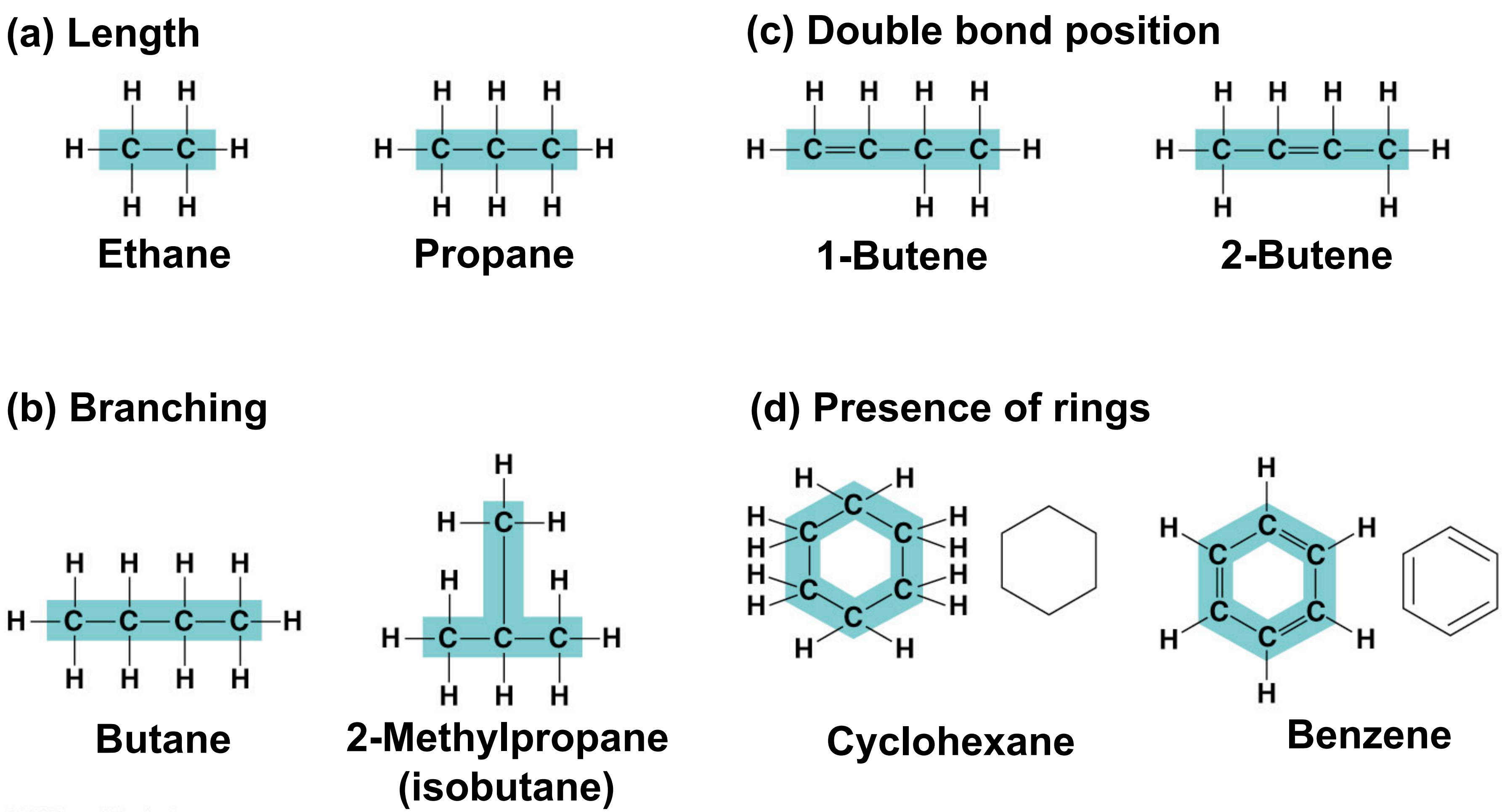

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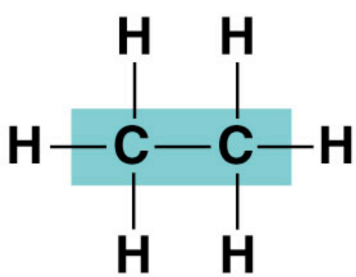
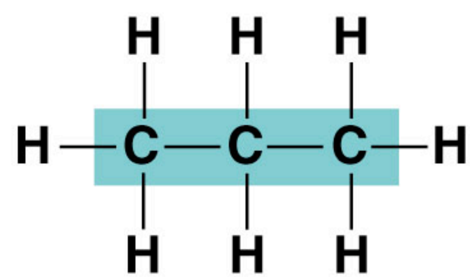
Figure 4.5a

(a) Length



Ethane



Propane

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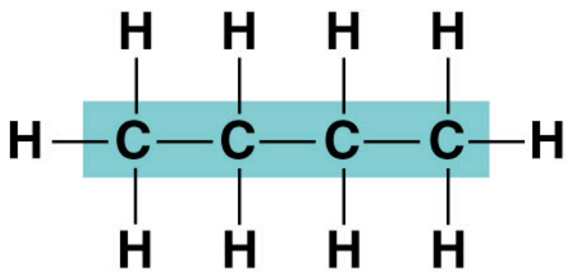
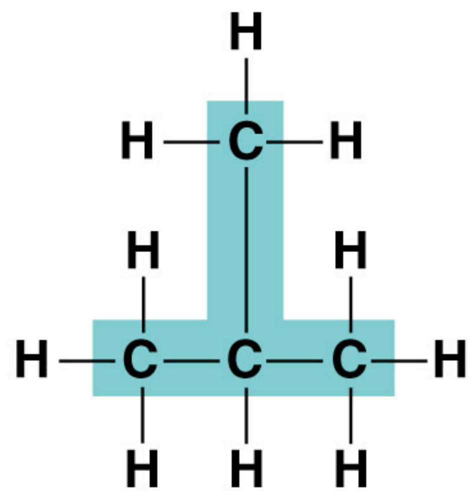
Figure 4.5b

(b) Branching



Butane



2-Methylpropane (commonly called isobutane)

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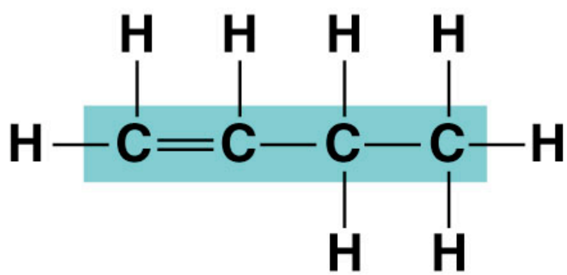
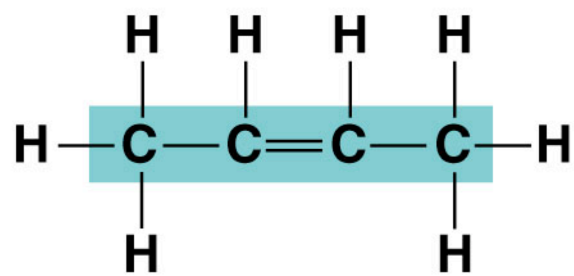
Figure 4.5c

(c) Double bond position



1-Butene



2-Butene

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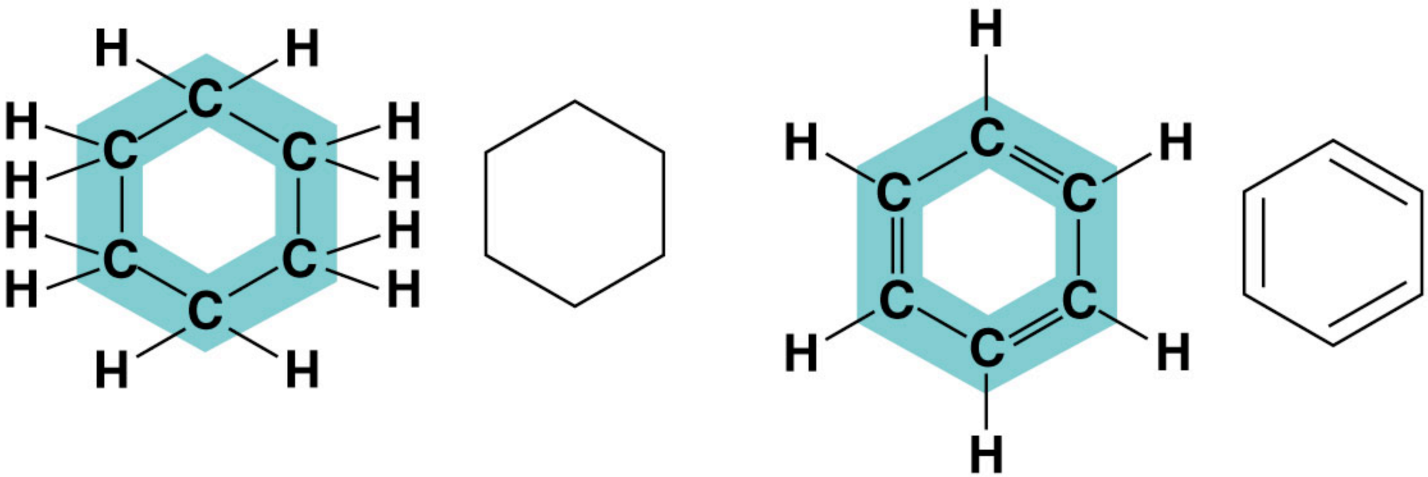
Figure 4.5d

(d) Presence of rings



Cyclohexane

Benzene

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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

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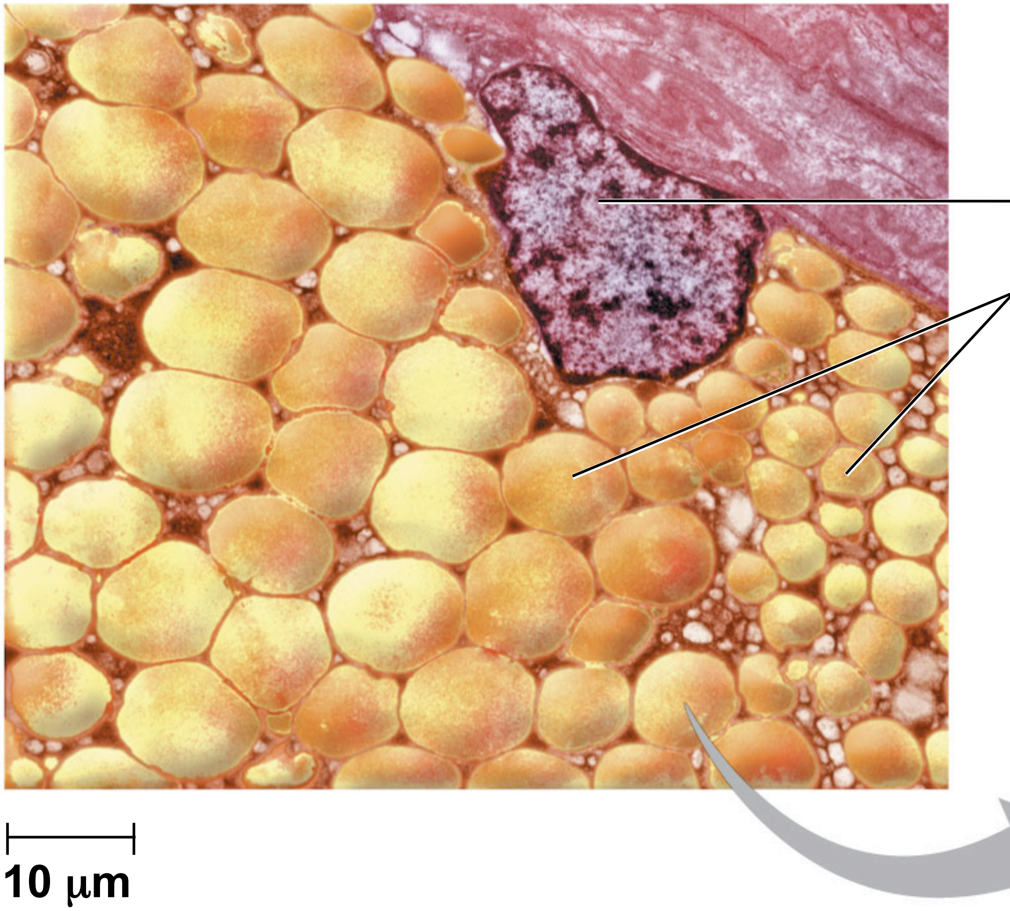
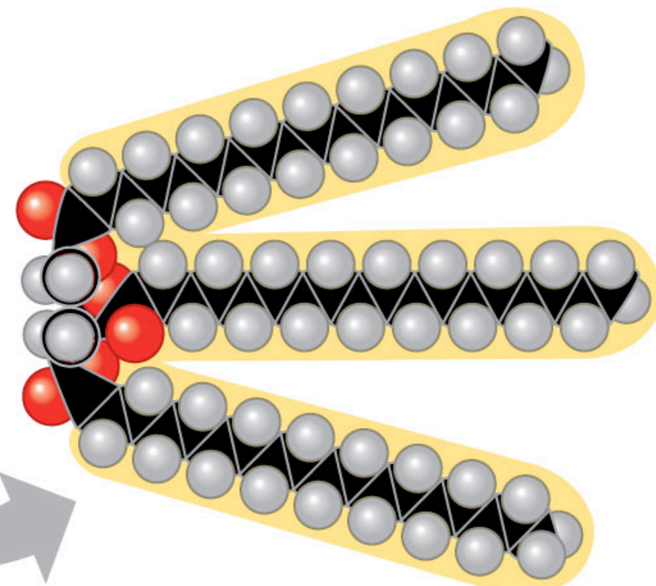
Figure 4.6



(a) Part of a human adipose cell



(b) A fat molecule

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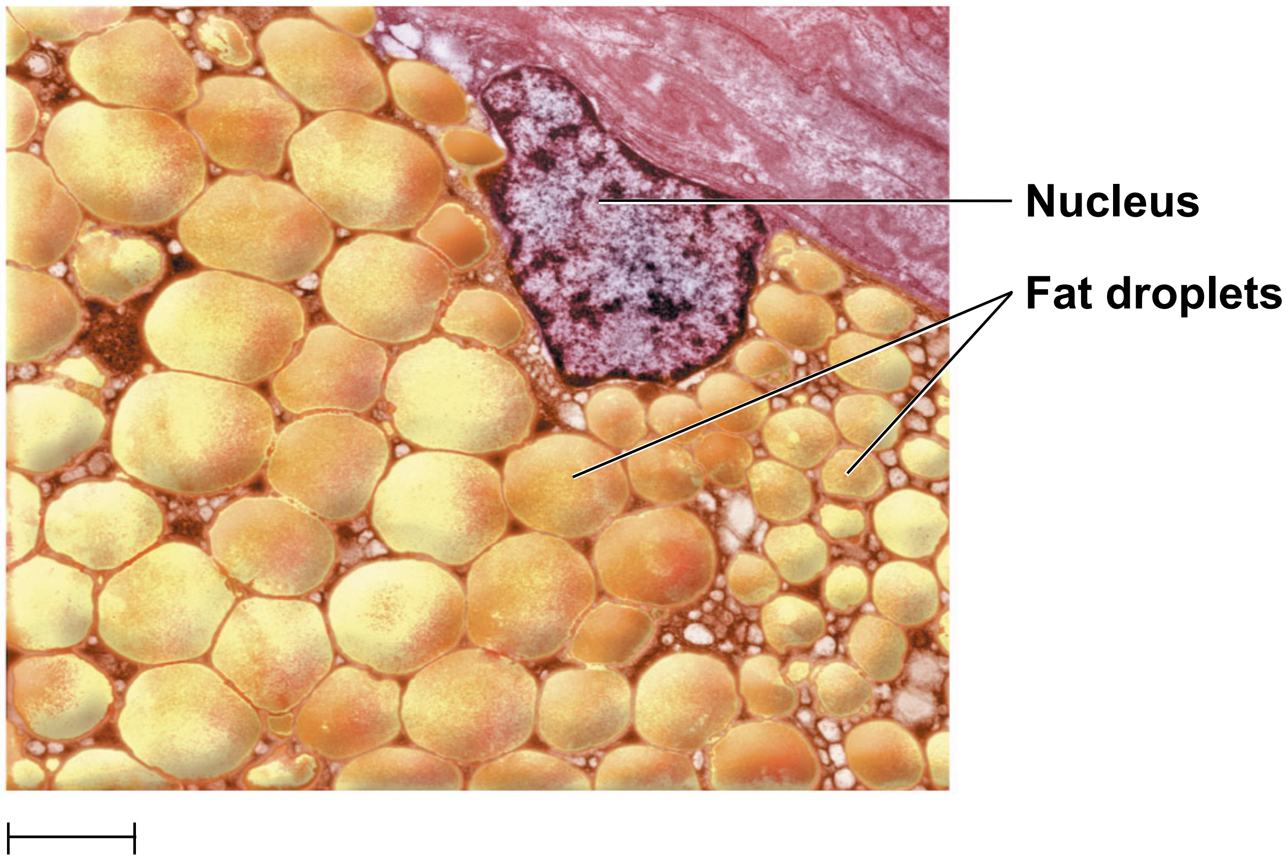
Figure 4.6a



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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

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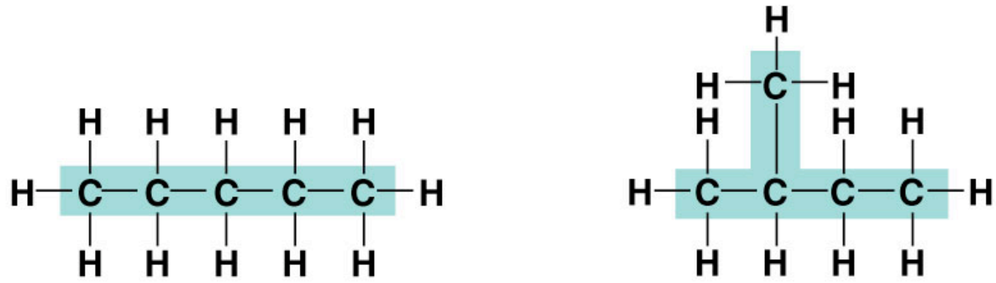
Figure 4.7

(a) Structural isomers

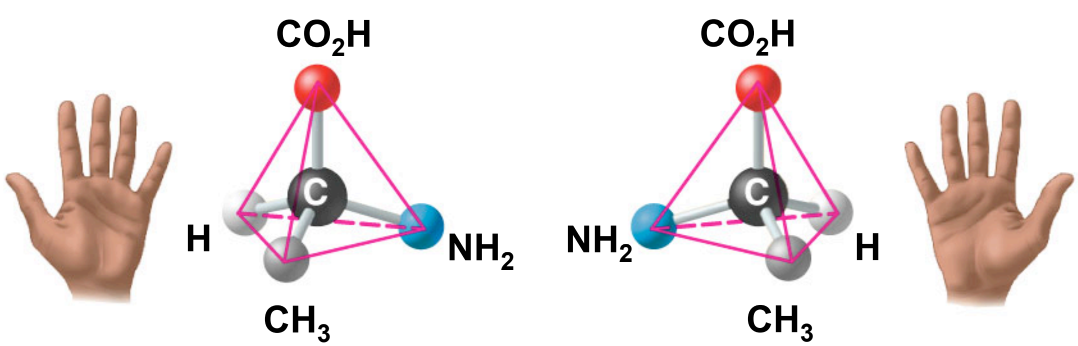


(b) *Cis-trans* isomers

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**

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Figure 4.7a

(a) Structural isomers

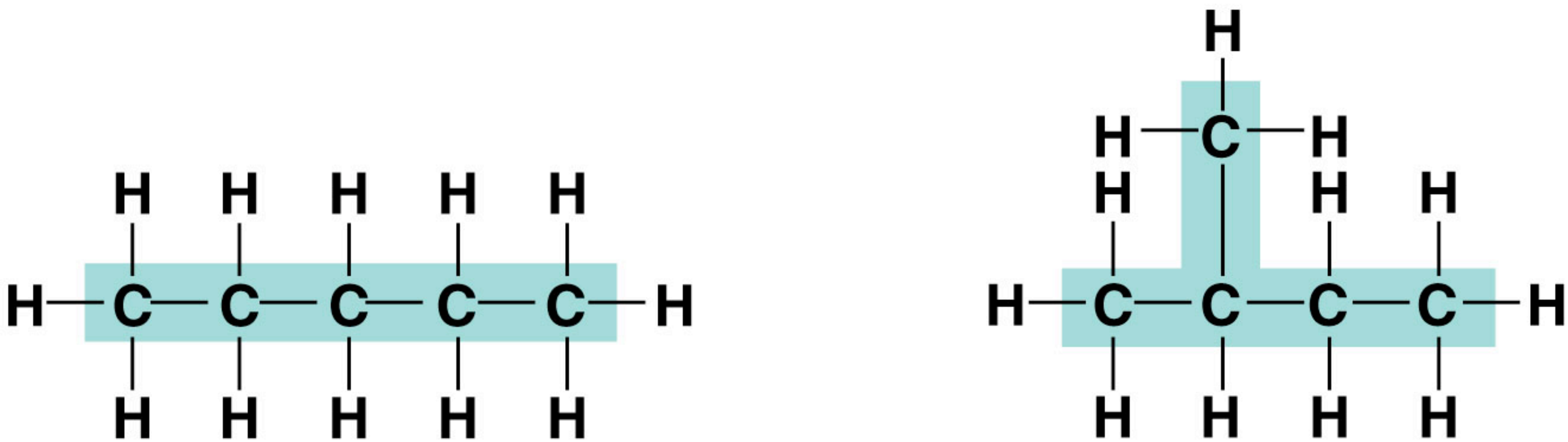

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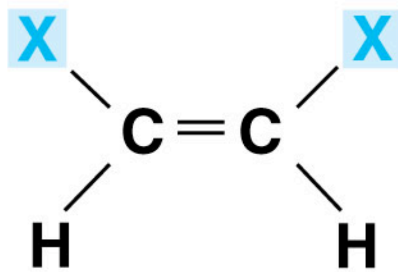
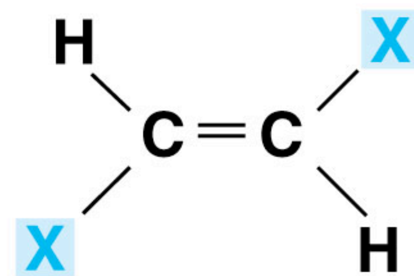
Figure 4.7b

(b) *Cis-trans* isomers



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



trans isomer: The two Xs are on opposite sides.

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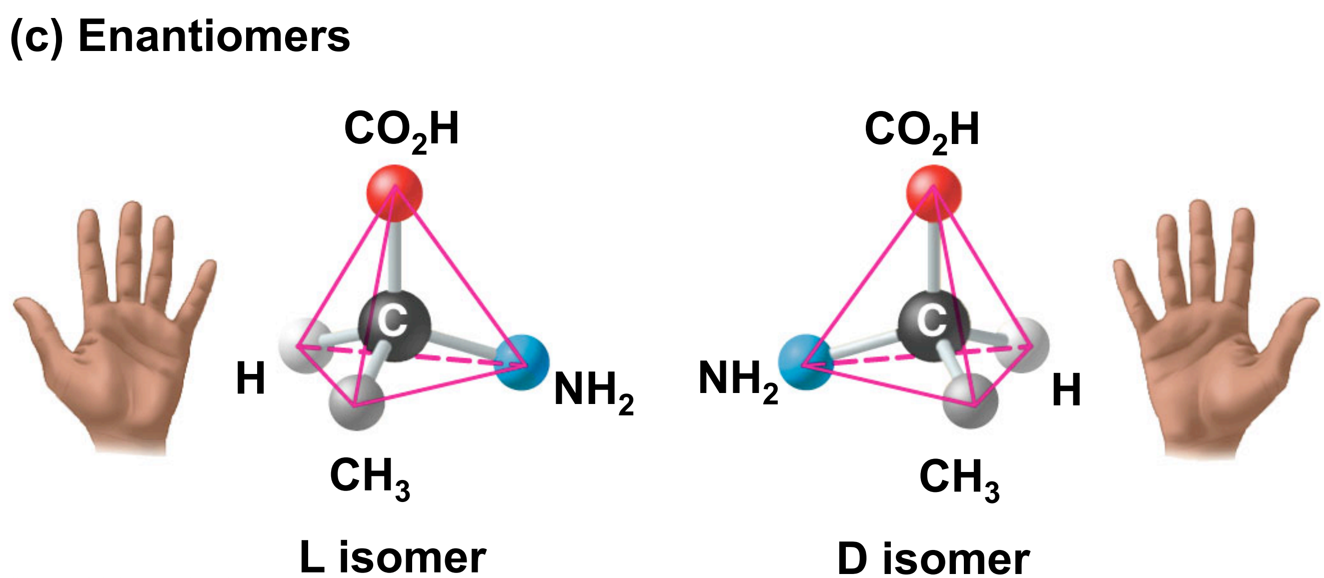
Figure 4.7c



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- 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

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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

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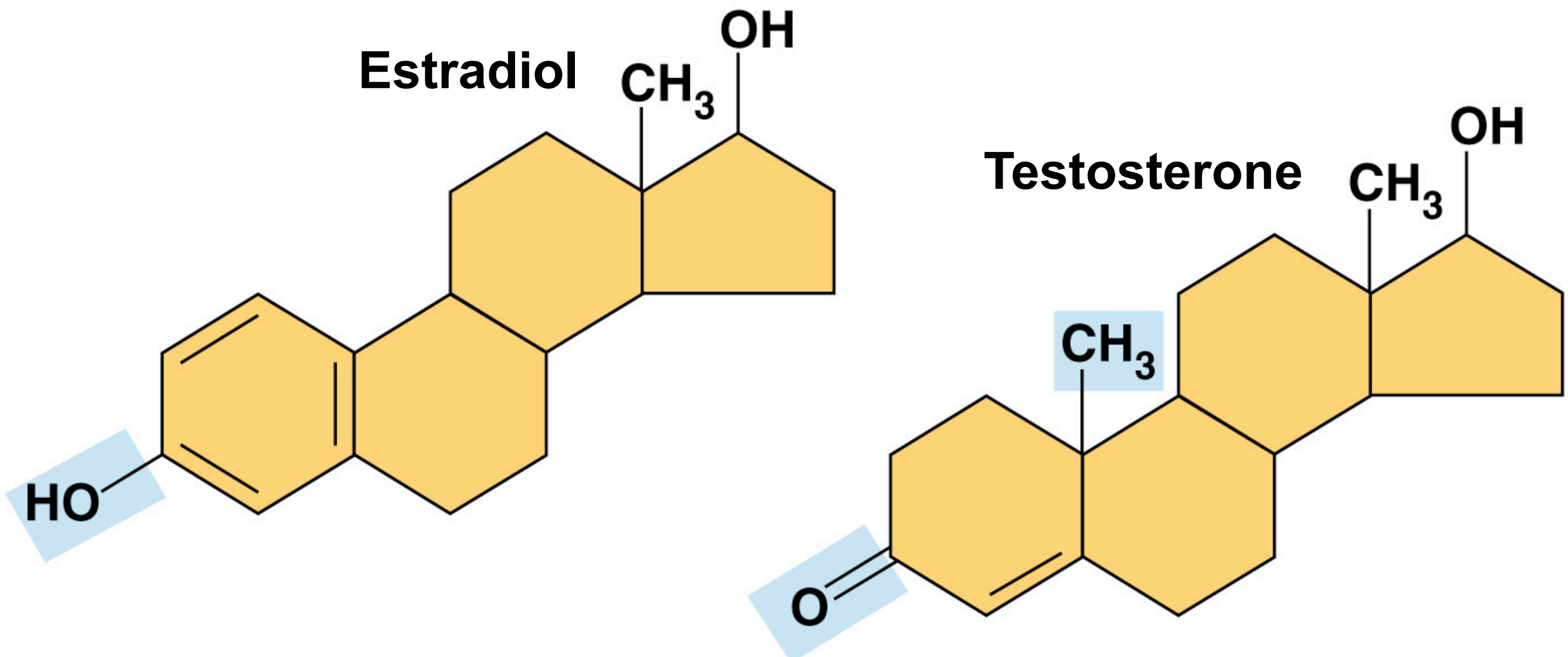
Figure 4.UN02



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- 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

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Figure 4.9-a

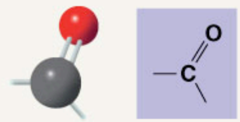
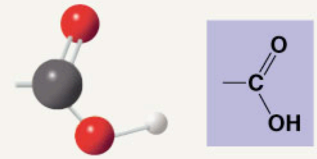
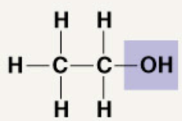
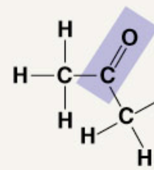
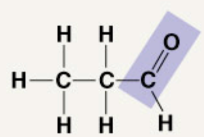
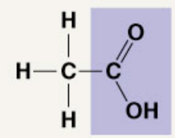
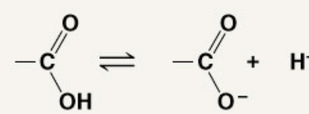
CHEMICAL GROUP	Hydroxyl	Carbonyl	Carboxyl
STRUCTURE	 (may be written HO—)		
NAME OF COMPOUND	Alcohols (Their specific names usually end in *-ol.)*	Ketones if the carbonyl group is within a carbon skeleton Aldehydes if the carbonyl group is at the end of the carbon skeleton	Carboxylic acids, or organic 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.

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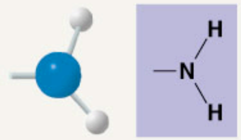
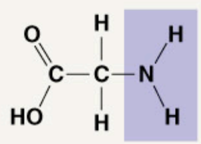
Figure 4.9-b

Amino



Amines



Glycine

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

$$H^+ + —NH_2 \rightleftharpoons —NH_3^+$$

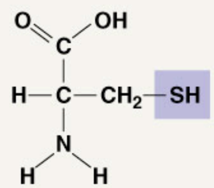
Nonionized   Ionized

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

Sulfhydryl

(may be written HS—)

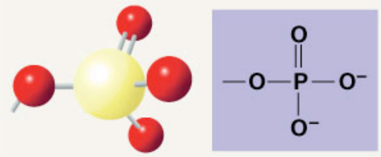
Thiols



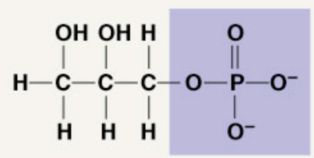
Cysteine

- 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.

Phosphate



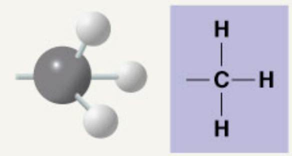
Organic phosphates



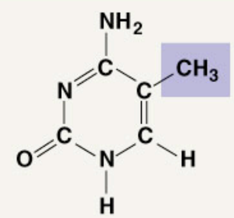
Glycerol phosphate

- 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.

Methyl



Methylated compounds



5-Methyl cytidine

- 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.

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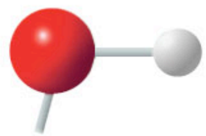
Figure 4.9a

Hydroxyl

STRUCTURE



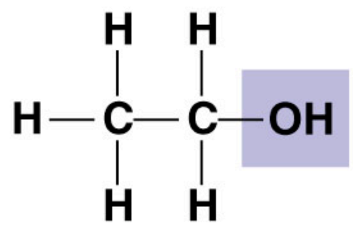
—OH

(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.

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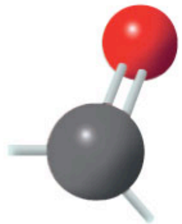
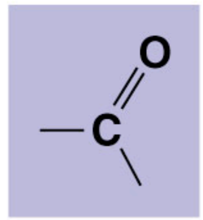
Figure 4.9b

Carbonyl

STRUCTURE



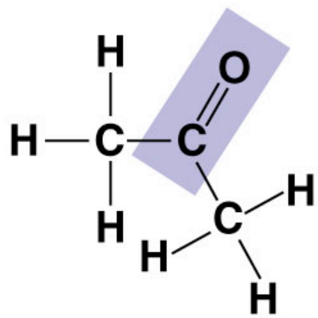


Ketones if the carbonyl group is within a carbon skeleton

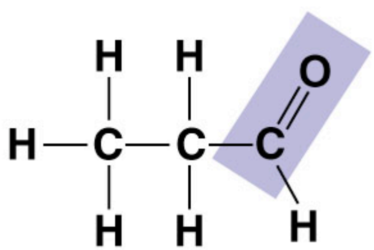
Aldehydes if the carbonyl group is at the end of the carbon skeleton

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

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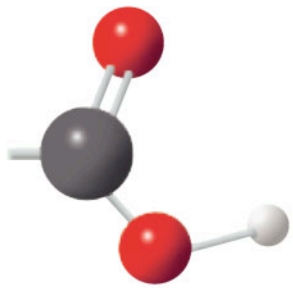
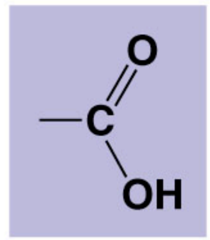
Figure 4.9c

Carboxyl

STRUCTURE

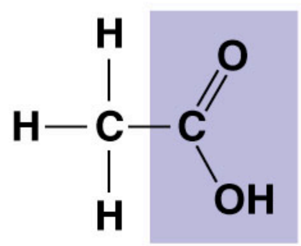




NAME OF COMPOUND

Carboxylic acids, or organic acids

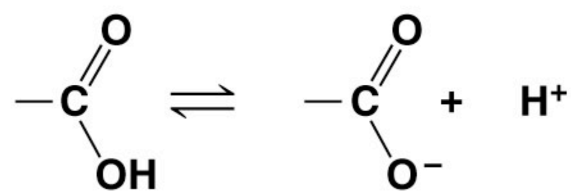
EXAMPLE



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.

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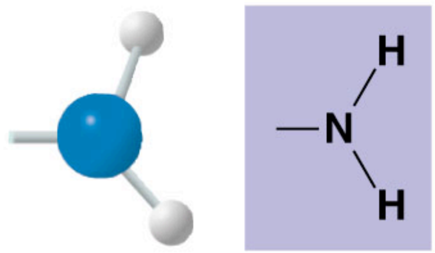
Figure 4.9d

Amino

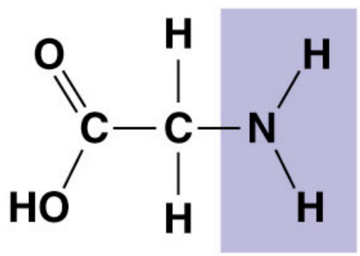
STRUCTURE



Amines

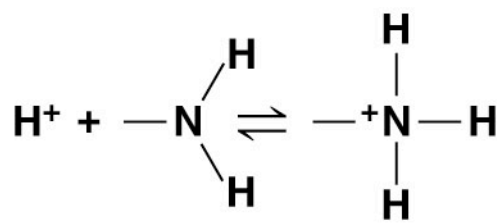
NAME OF COMPOUND

EXAMPLE



Glycine

- **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+.**

FUNCTIONAL PROPERTIES

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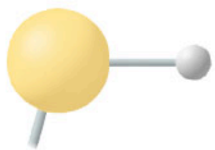
Figure 4.9e

Sulfhydryl

STRUCTURE



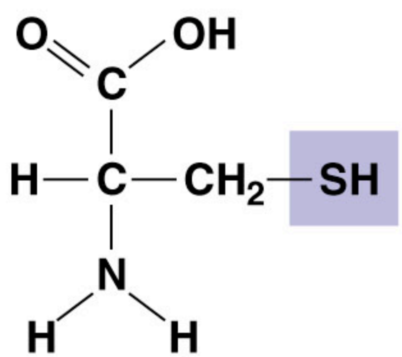
—SH

(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.

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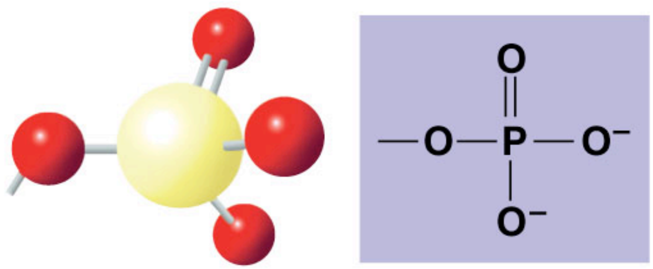
Figure 4.9f

Phosphate

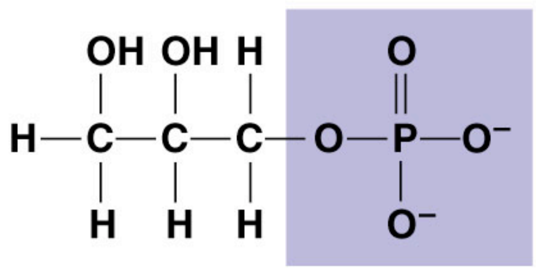
STRUCTURE



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.

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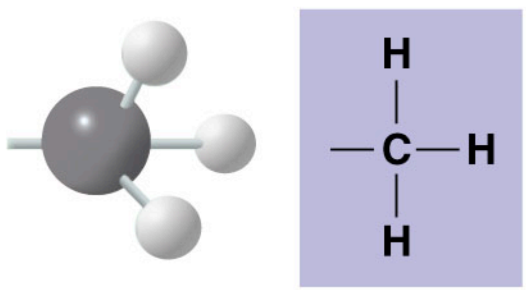
Figure 4.9g

Methyl

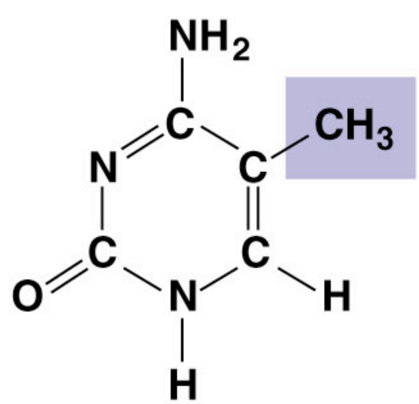
STRUCTURE



NAME OF COMPOUND

Methylated compounds

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.

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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

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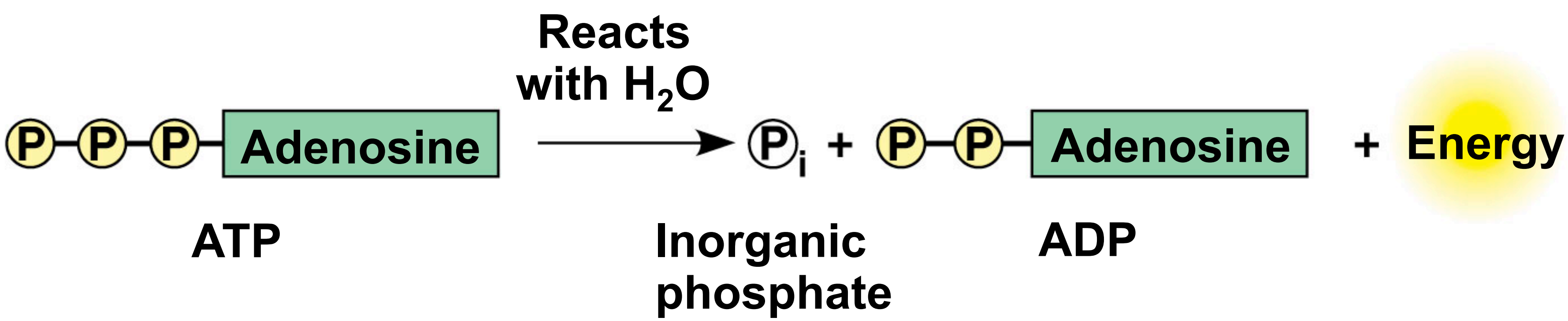
Figure 4. UN05



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