Chapter 4

Carbon and the Molecular Diversity of Life

PowerPoint® Lecture Presentations for

Biology

Eighth Edition

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Overview: Carbon: The Backbone of Life

- Although cells are 70–95% water, the rest consists 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

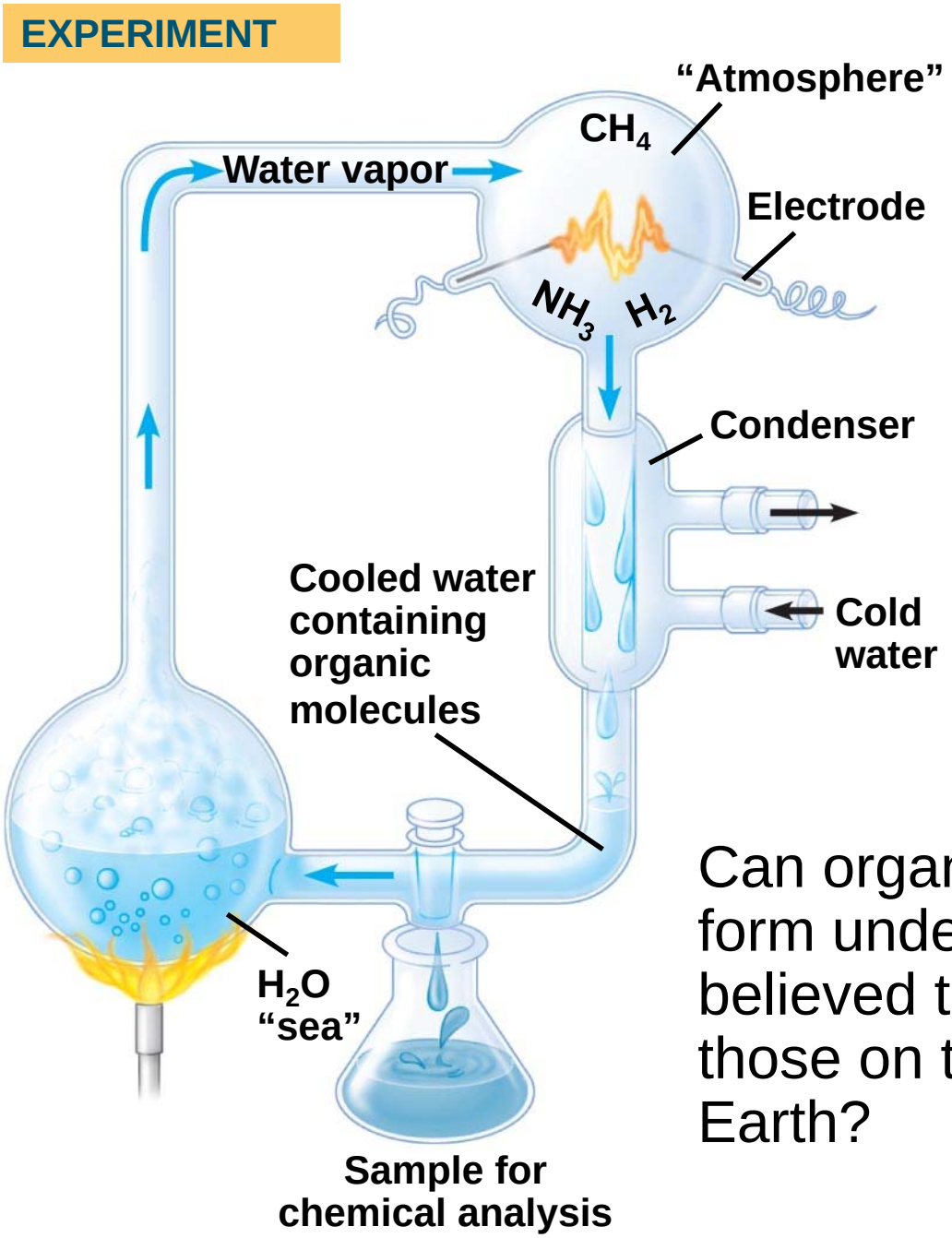
Fig. 4-1

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

Fig. 4-2



Can organic molecules form under conditions believed to simulate those on the early Earth?

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

- With four valence electrons, carbon can form four covalent bonds with a variety of atoms
- This *tetravalence* 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 molecule has a flat shape

Fig. 4-3

The shapes of three simple organic molecules

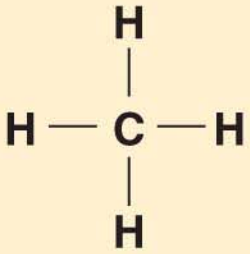
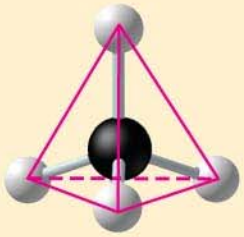
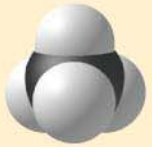
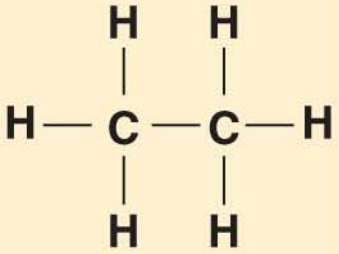
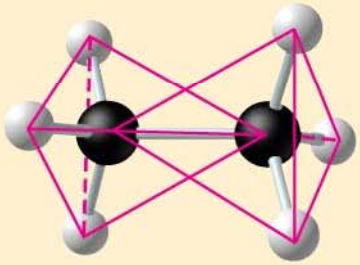
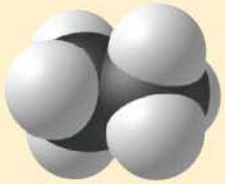
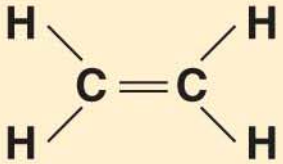
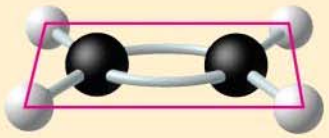
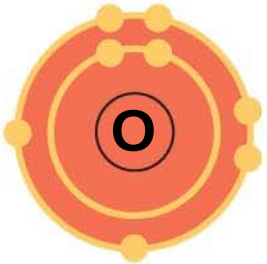
Name	Molecular Formula	Structural Formula	Ball-and-Stick Model	Space-Filling Model
(a) Methane	CH_4			
(b) Ethane	C_2H_6			
(c) Ethene (ethylene)	C_2H_4			

Fig. 4-4

Valences of the major elements of organic molecules

Hydrogen (valence = 1)

Oxygen (valence = 2)



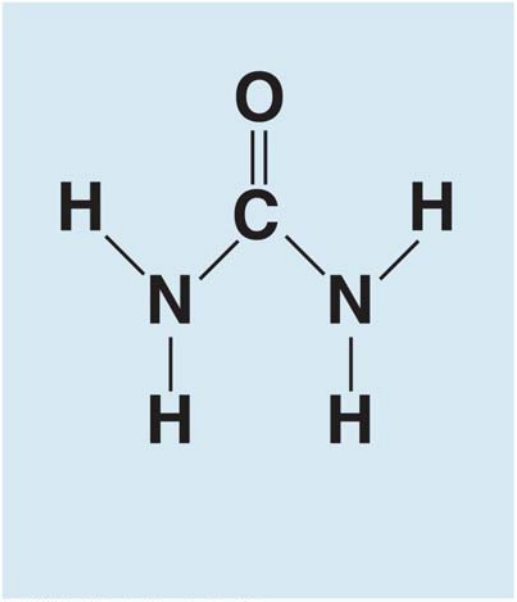
Nitrogen (valence = 3)

Carbon (valence = 4)

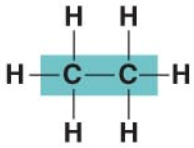
- Carbon atoms can partner with atoms other than hydrogen; for example:
  - Carbon dioxide: CO_2

$$O = C = O$$

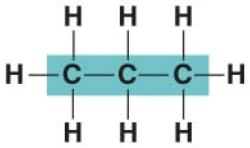
  - Urea: $CO(NH_2)_2$



Molecular Diversity Arising from Carbon Skeleton Variation

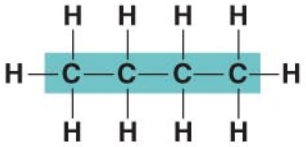


Ethane

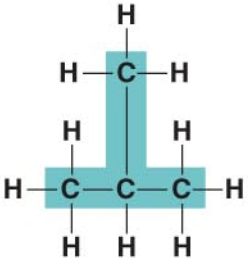


Propane

(a) Length

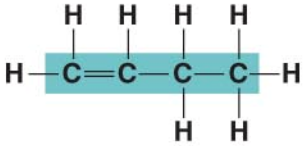


Butane

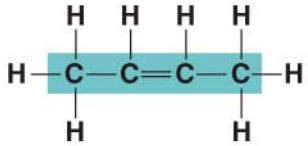


2-Methylpropane
(commonly called isobutane)

(b) Branching

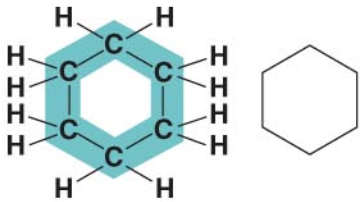


1-Butene

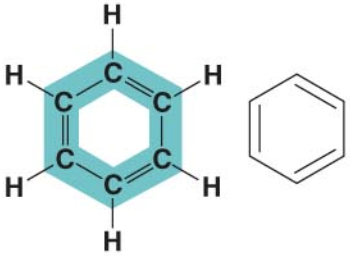


2-Butene

(c) Double bonds



Cyclohexane



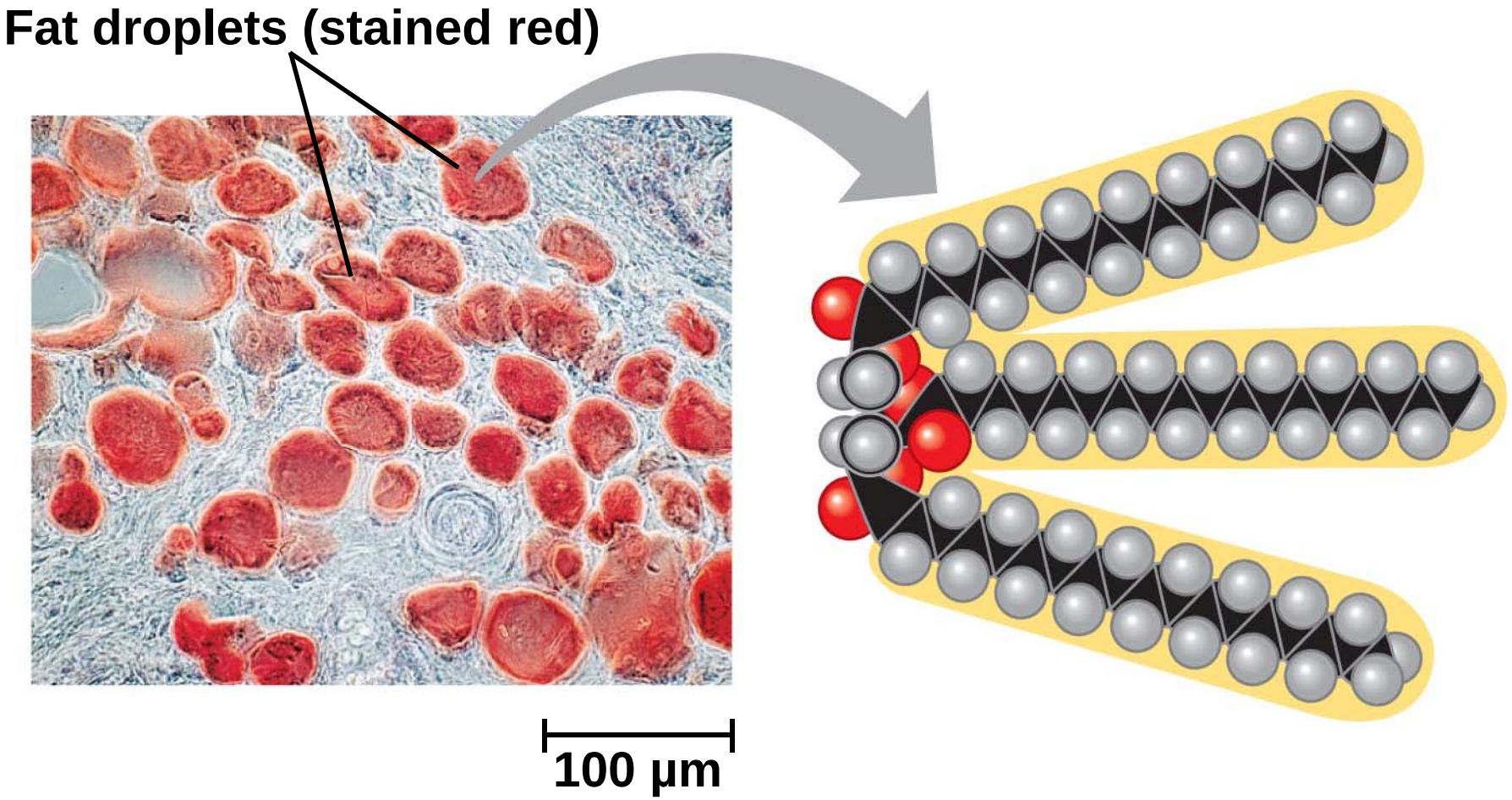
Benzene

(d) Rings

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

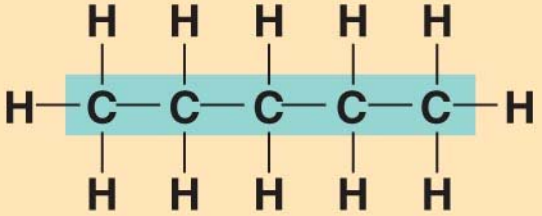
Fig. 4-6



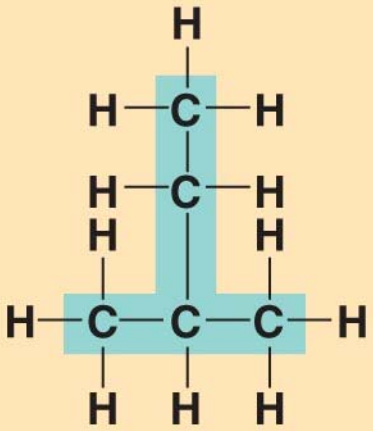
Isomers

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

Fig. 4-7a



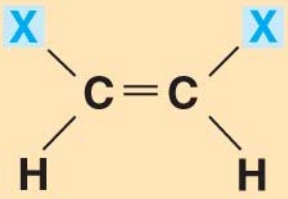
Pentane



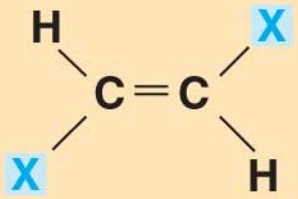
2-methyl butane

(a) Structural isomers

Fig. 4-7b



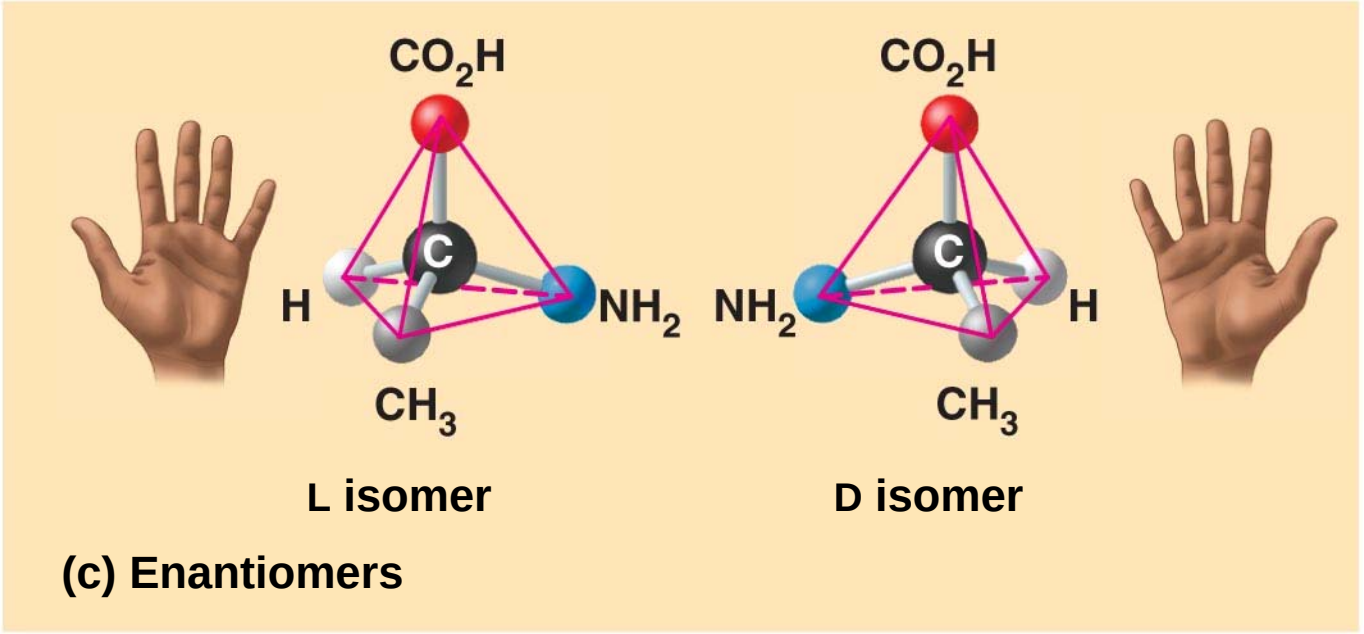
***cis* isomer: The two Xs are on the same side.**



***trans* isomer: The two Xs are on opposite sides.**

(b) Geometric isomers

Fig. 4-7c



- Enantiomers are important in the pharmaceutical industry
- Two enantiomers of a drug may have different effects
- Differing effects of enantiomers demonstrate that organisms are sensitive to even subtle variations in molecules

Fig. 4-8

The pharmacological importance of enantiomers

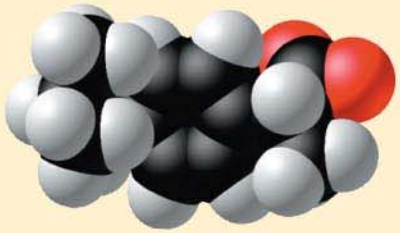
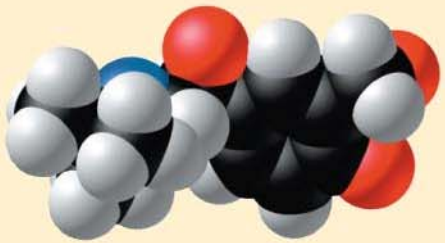
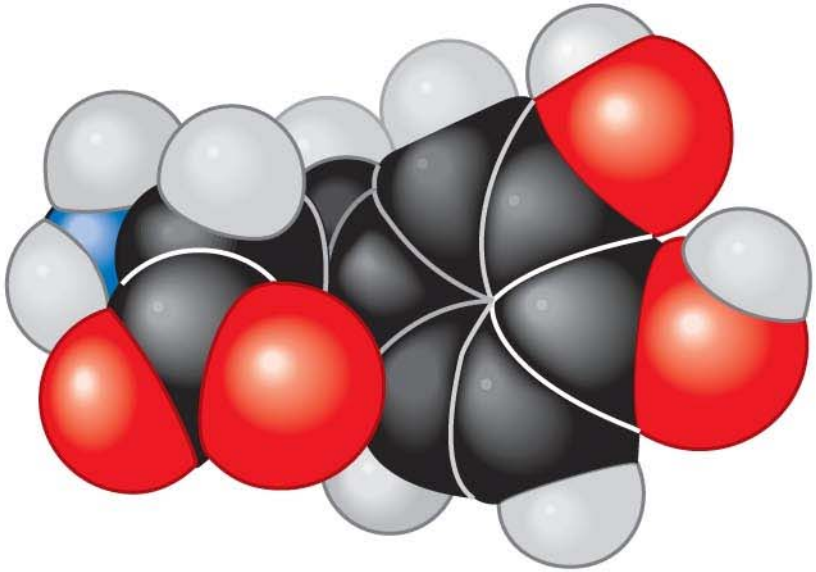
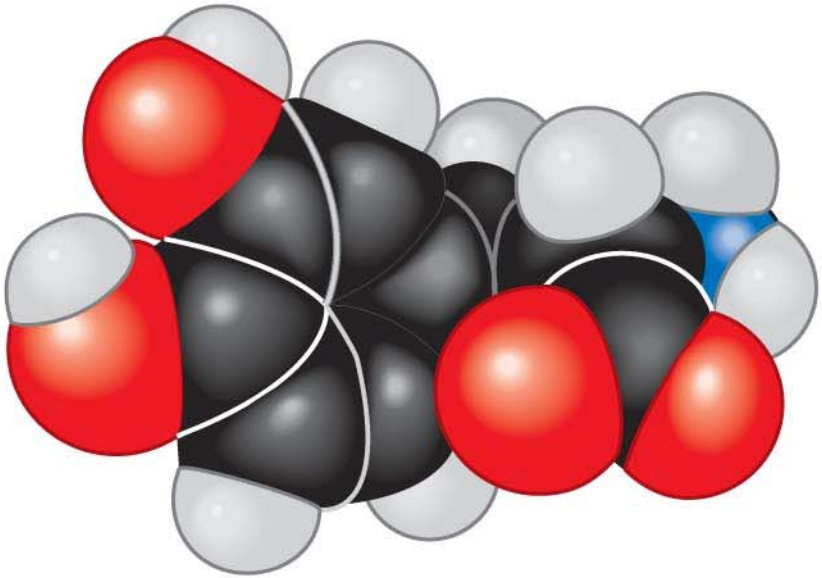
Drug	Condition	Effective Enantiomer	Ineffective Enantiomer
Ibuprofen	Pain; inflammation	 *S*-Ibuprofen	 *R*-Ibuprofen
Albuterol	Asthma	 *R*-Albuterol	 *S*-Albuterol

Fig. 4-UN9



L-dopa



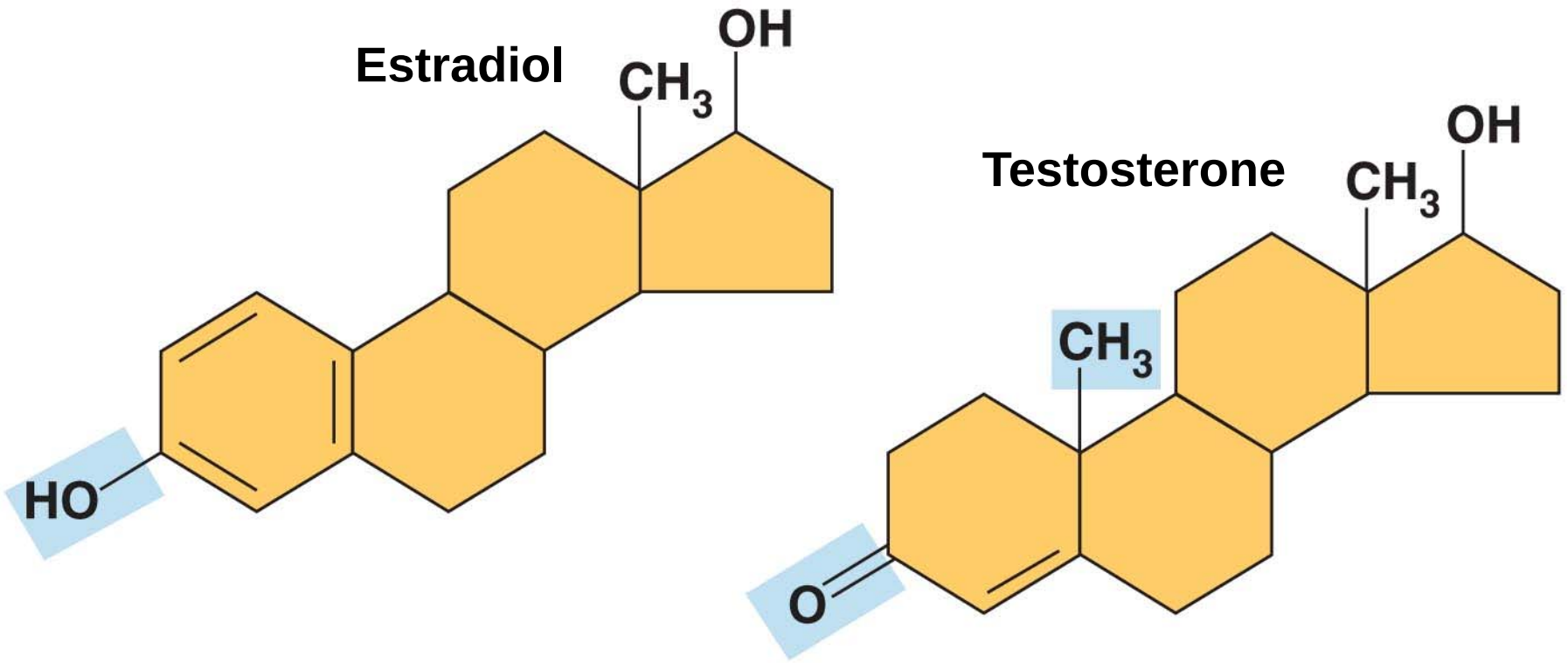
D-dopa

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

- **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

Fig. 4-9

A comparison of chemical groups of female (estradiol) and male (testosterone) sex hormones

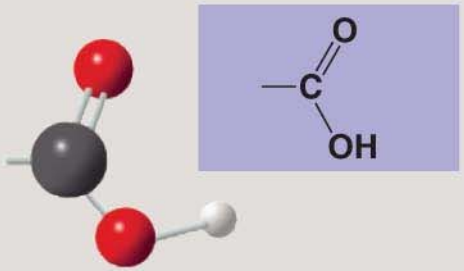


- The seven functional groups that are most important in the chemistry of life:
  - Hydroxyl group
  - Carbonyl group
  - Carboxyl group
  - Amino group
  - Sulfhydryl group
  - Phosphate group
  - Methyl group

Fig. 4-10c

Carboxyl

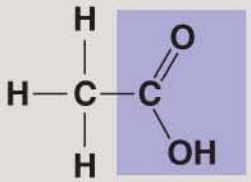
STRUCTURE



NAME OF COMPOUND

Carboxylic acids, or organic acids

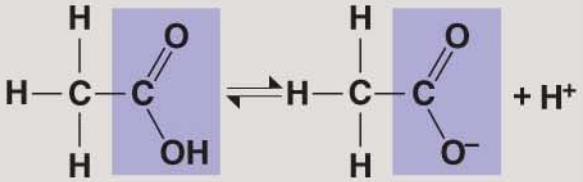
EXAMPLE



Acetic acid, which gives vinegar its sour taste

FUNCTIONAL PROPERTIES

- **Has acidic properties because the covalent bond between oxygen and hydrogen is so polar; for example,**



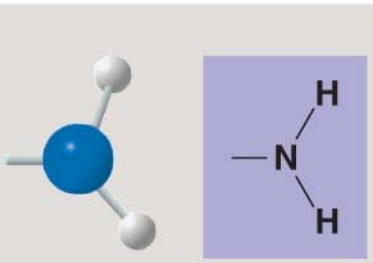
Acetic acid **Acetate ion**

- **Found in cells in the ionized form with a charge of 1– and called a carboxylate ion (here, specifically, the acetate ion).**

Fig. 4-10d

Amino

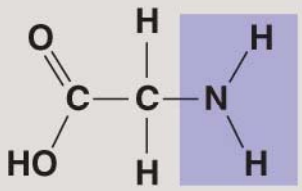
STRUCTURE



NAME OF COMPOUND

Amines

EXAMPLE

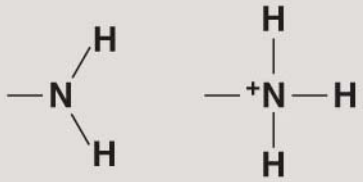


Glycine

Because it also has a carboxyl group, glycine is both an amine and a carboxylic acid; compounds with both groups are called amino acids.

FUNCTIONAL PROPERTIES

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



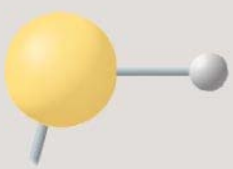
(nonionized) (ionized)

- **Ionized, with a charge of 1+, under cellular conditions.**

Fig. 4-10e

Sulfhydryl

STRUCTURE



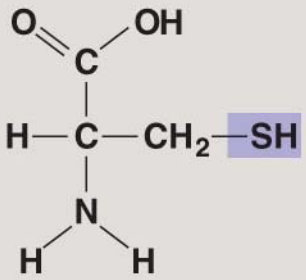
—SH

(may be written HS—)

NAME OF COMPOUND

Thiols

EXAMPLE



Cysteine

Cysteine is an important sulfur-containing amino acid.

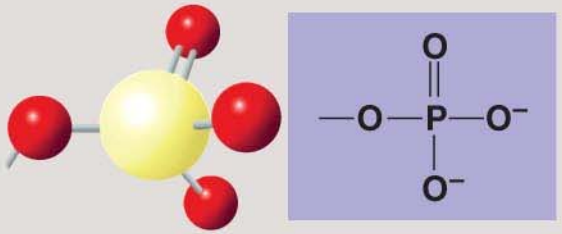
FUNCTIONAL PROPERTIES

- 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, then breaking and re-forming the cross-linking bonds.

Fig. 4-10f

Phosphate

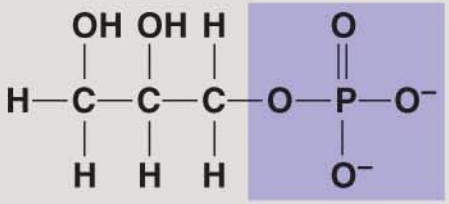
STRUCTURE



NAME OF COMPOUND

Organic phosphates

EXAMPLE



Glycerol phosphate

In addition to taking part in many important chemical reactions in cells, glycerol phosphate provides the backbone for phospholipids, the most prevalent molecules in cell membranes.

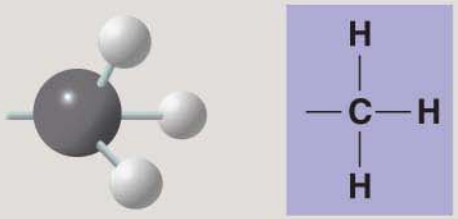
FUNCTIONAL PROPERTIES

- **Contributes negative charge to the molecule of which it is a part (2– when at the end of a molecule; 1– when located internally in a chain of phosphates).**
- **Has the potential to react with water, releasing energy.**

Fig. 4-10g

Methyl

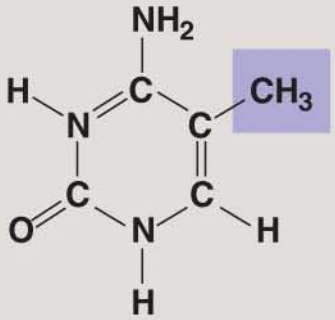
STRUCTURE



NAME OF COMPOUND

Methylated compounds

EXAMPLE



5-Methyl cytidine

5-Methyl cytidine is a component of DNA that has been modified by addition of the methyl group.

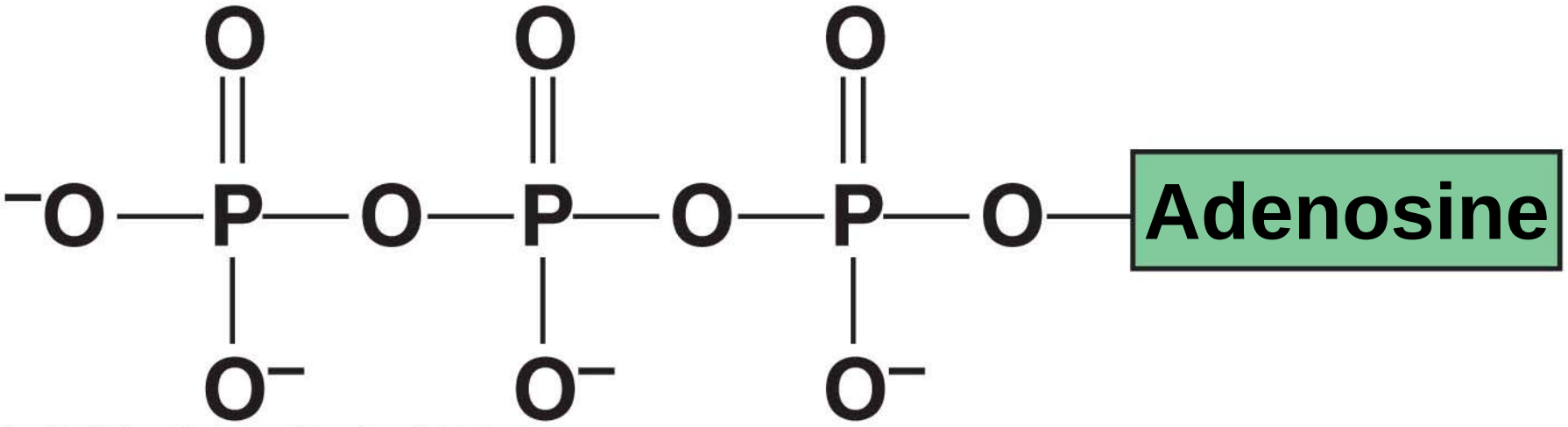
FUNCTIONAL PROPERTIES

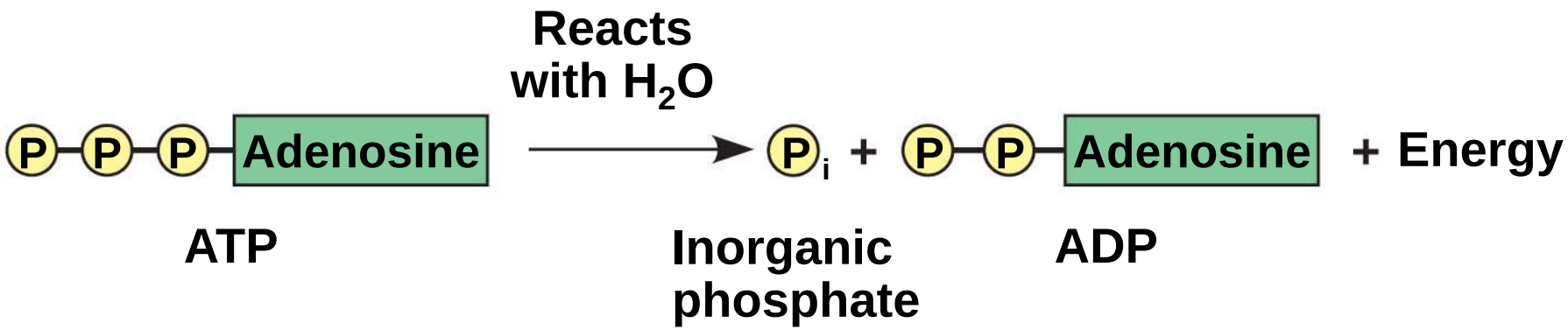
- **Addition of a methyl group to DNA, or to molecules bound to DNA, affects expression of genes.**
- **Arrangement of methyl groups in male and female sex hormones affects their shape and function.**

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

Fig. 4-UN4





You should now be able to:

1. Explain how carbon's electron configuration explains its ability to form large, complex, diverse organic molecules
2. Describe how carbon skeletons may vary and explain how this variation contributes to the diversity and complexity of organic molecules
3. Distinguish among the three types of isomers: structural, geometric, and enantiomer

4. Name the major functional groups found in organic molecules; describe the basic structure of each functional group and outline the chemical properties of the organic molecules in which they occur

5. Explain how ATP functions as the primary energy transfer molecule in living cells