Carbon and the Molecular Diversity of Life

Chapter 4.1-4.3

Carbon: The Backbone of Life

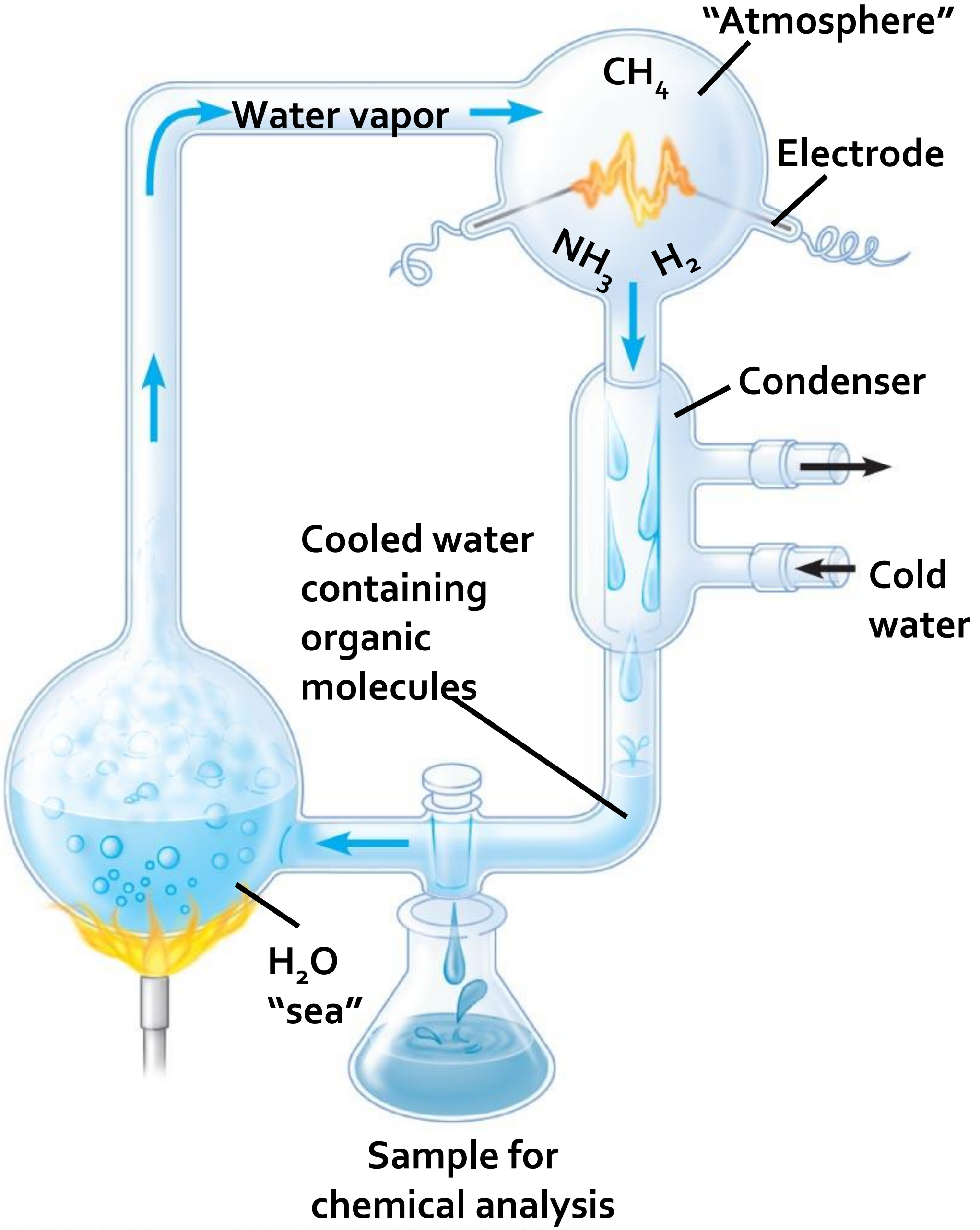
- Although cells are 70–95% water, the rest consists mostly of carbon-based compounds
  - Why? It can form large, complex, and diverse molecules
  - Proteins, DNA, carbohydrates, and other molecules found in living matter are made of C

Organic chemistry

- **Organic chemistry** is the study of compounds that contain carbon
  - Most also contain hydrogen atoms in addition to carbon atoms
- Scientists used to believe that organic chemistry and inorganic chemistry were completely separate

Fig. 4-2

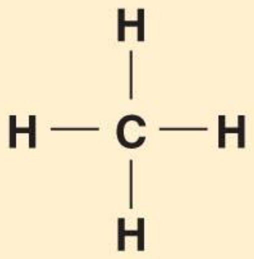
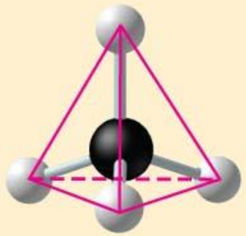
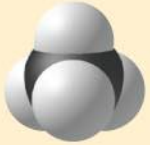
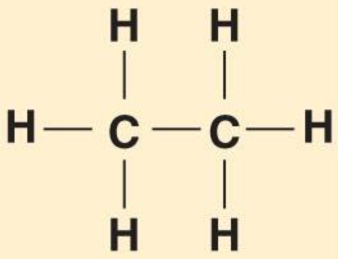
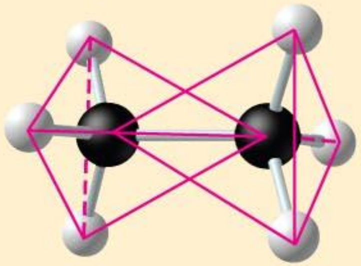
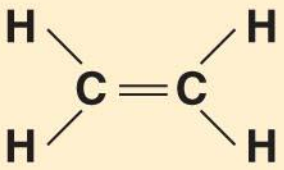
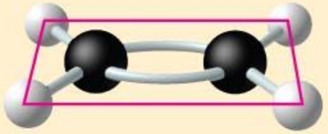
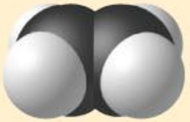
EXPERIMENT

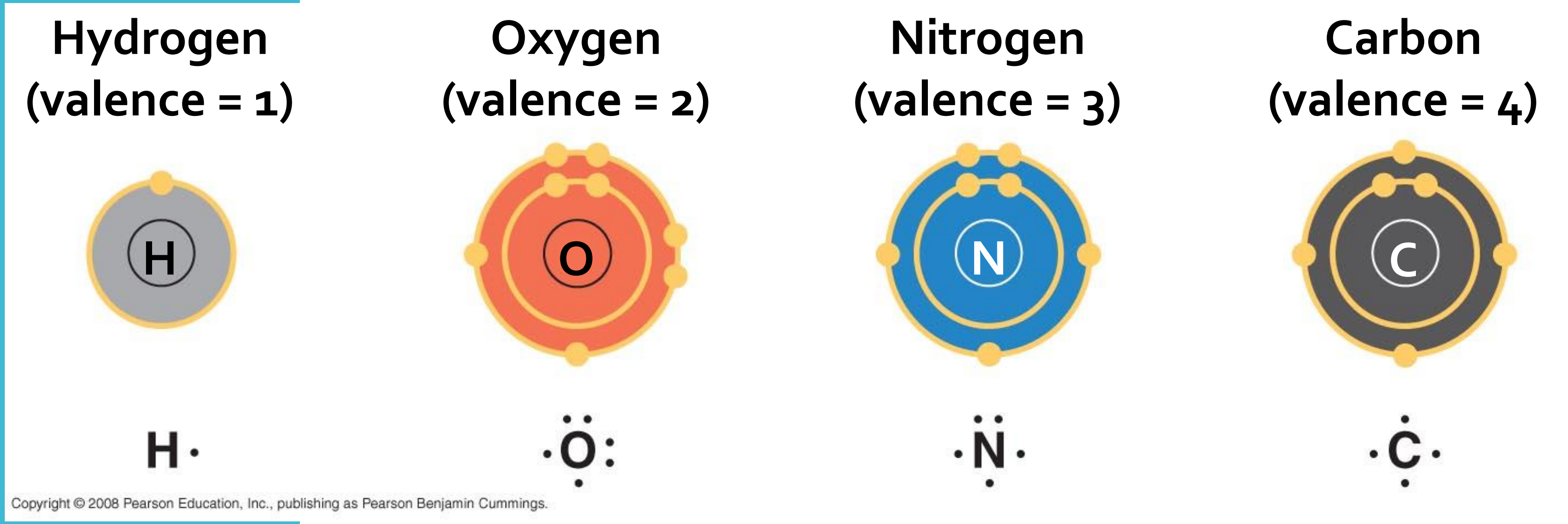


How is Carbon able to form such a diverse collection of molecules?

- Electron configuration is the key to an atom's characteristics
  - determines the kinds and number of bonds an atom will form with other atoms
- With four valence electrons, carbon can form four covalent bonds with a variety of atoms
- This is called *tetravalence* and 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

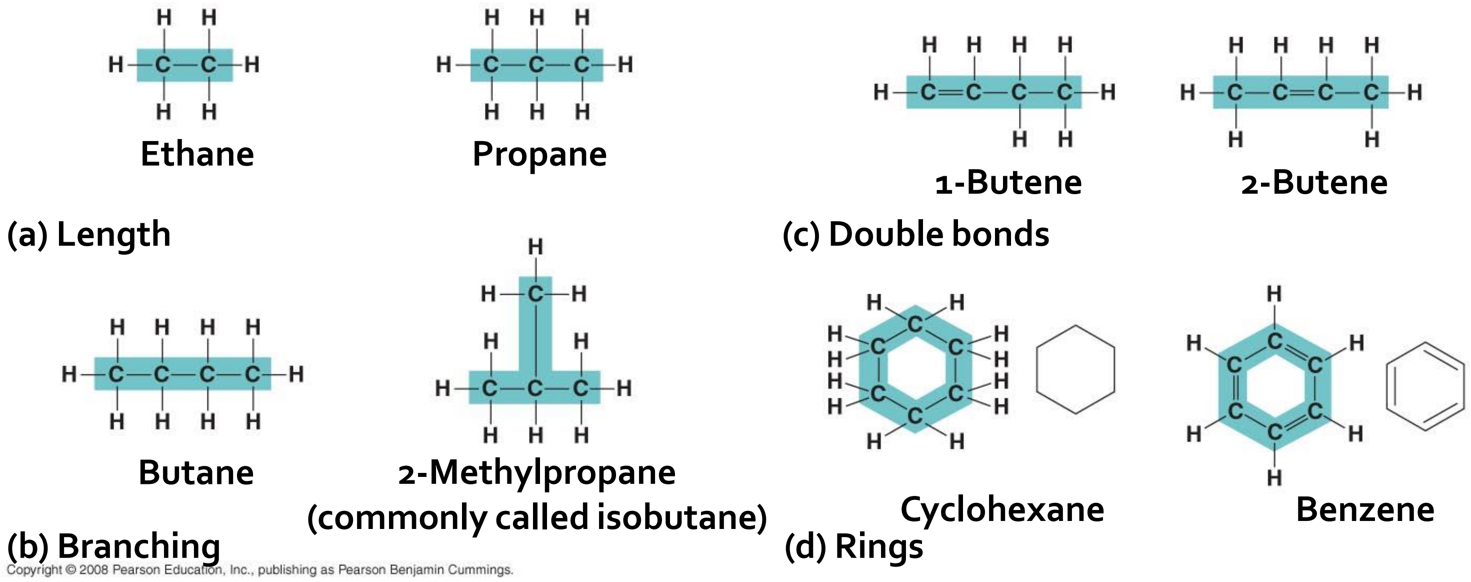
Fig. 4-3

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			


Hydrogen
(valence = 1)
Oxygen
(valence = 2)
Nitrogen
(valence = 3)
Carbon
(valence = 4)
H
O
N
C
H·
·Ö:
·N̈·
·Ċ·

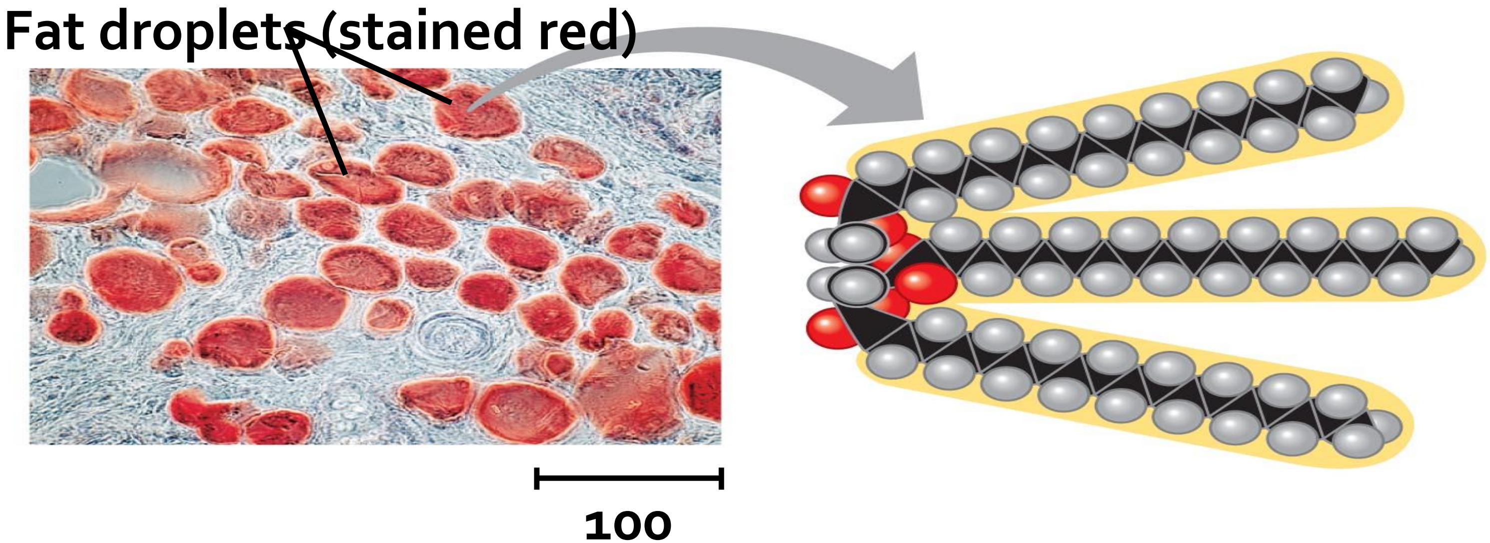
Carbon's ability to form a variety of different bonds can lead to the creation of "carbon skeletons"

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



Hydrocarbons

- 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
  - Fuels like propane are hydrocarbons
  - So are fats in our bodies

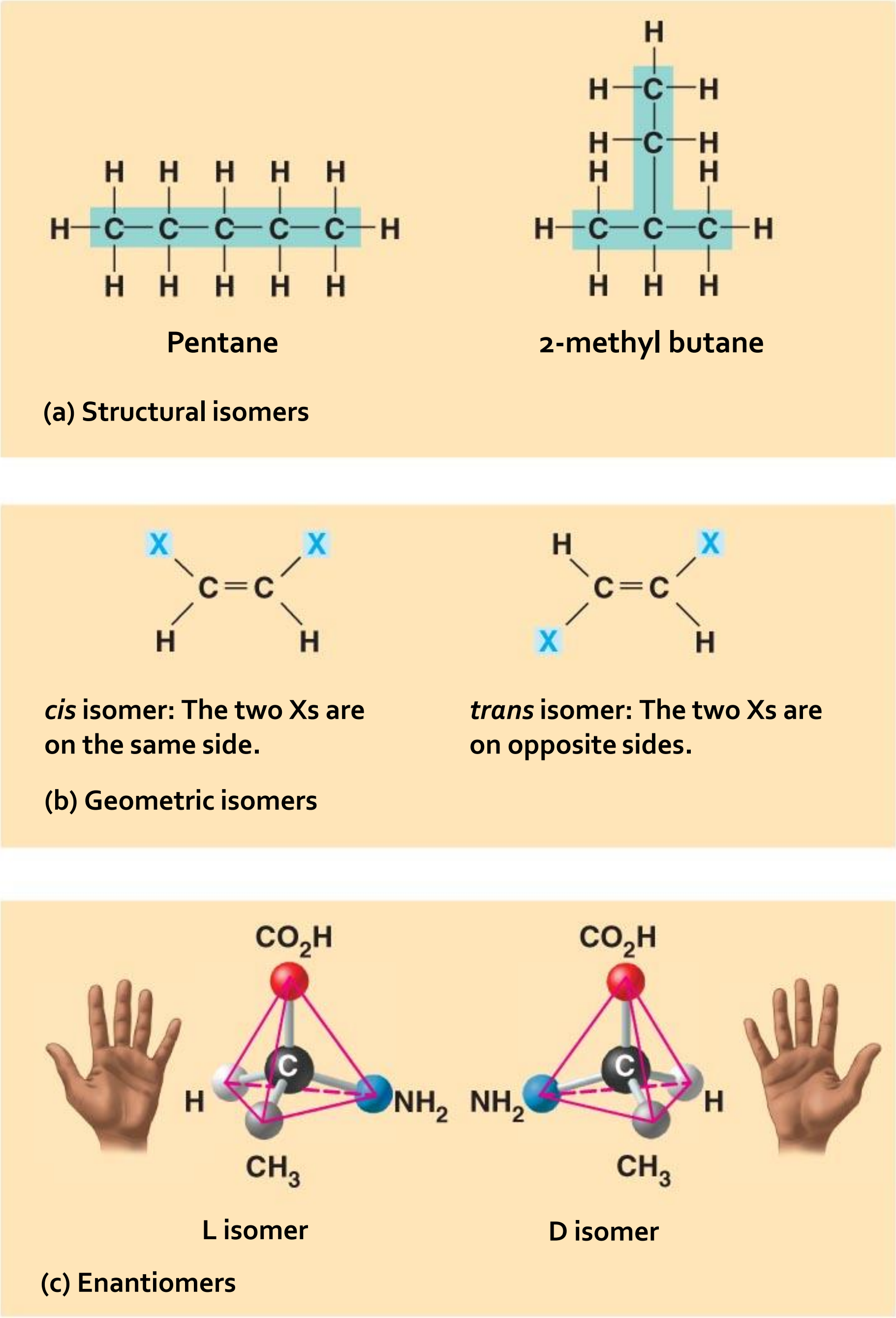


(a) Mammalian adipose cells

(b) A fat molecule

Isomers

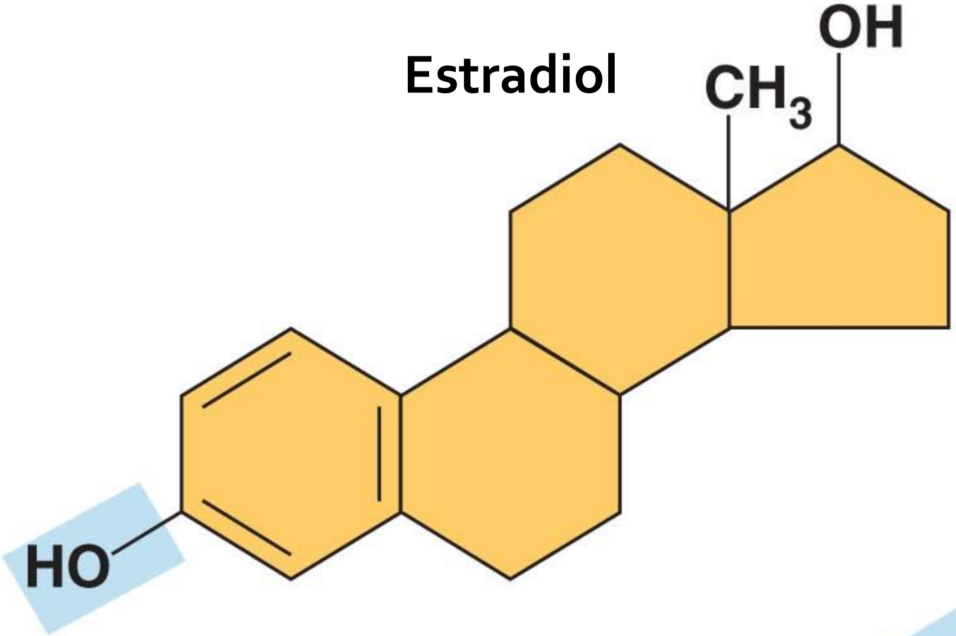
- **Isomers** are compounds with the same molecular formula but different structures and properties:
  - **Structural isomers** have different covalent arrangements of their atoms
  - **Geometric isomers (may also be called cis-trans isomers)** have the same covalent arrangements but differ in spatial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


Pentane
2-methyl butane
(a) Structural isomers
cis isomer: The two Xs are on the same side.
trans isomer: The two Xs are on opposite sides.
(b) Geometric isomers
CO_2H
NH_2
CH_3
L isomer
D isomer
(c) Enantiomers

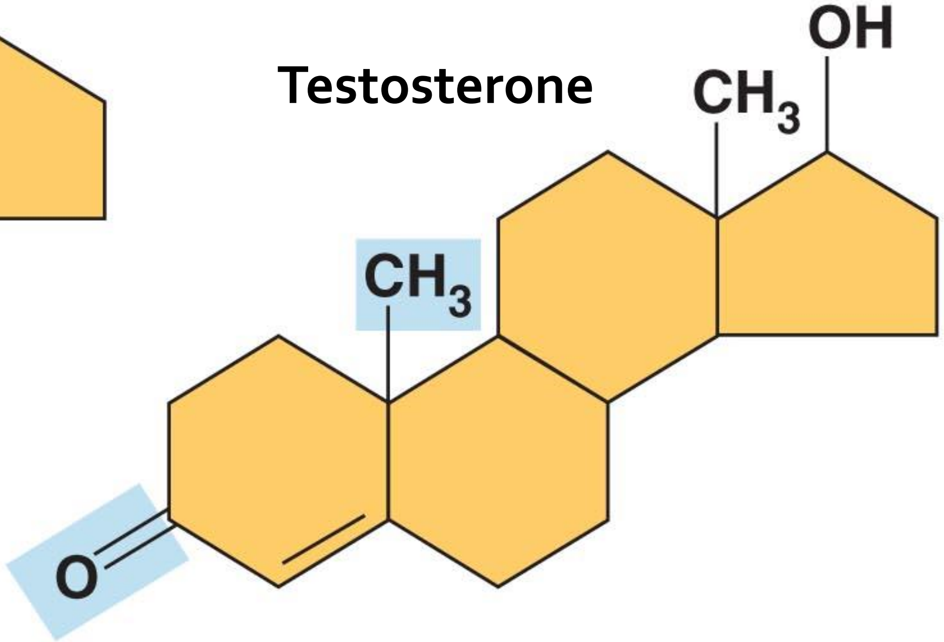
Chemical functional groups are key to the functioning of biological molecules

- Distinctive properties of organic molecules depend not only on the carbon skeleton but also on the molecular components attached to it
- **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

Estradiol



Testosterone

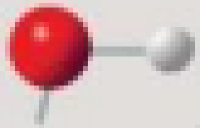


Important Functional Groups in Biology

- 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

Hydroxyl group

Hydroxyl

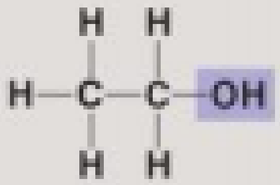


—OH

(may be written HO—)

In a hydroxyl group (—OH), a hydrogen atom is bonded to an oxygen atom, which in turn is bonded to the carbon skeleton of the organic molecule. (Do not confuse this functional group with the hydroxide ion, OH^-.)

Alcohols (their specific names usually end in *-ol*)



Ethanol, the alcohol present in alcoholic beverages

- 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.

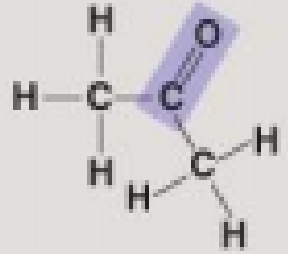
Carbonyl group

Carbonyl

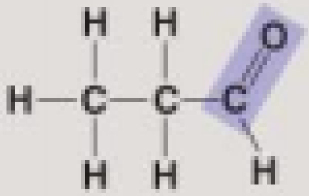
The carbonyl group (C=O) consists of a carbon atom joined to an oxygen atom by a double bond.

Ketones if the carbonyl group is within a carbon skeleton

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



Acetone, the simplest ketone



Propanal, an aldehyde

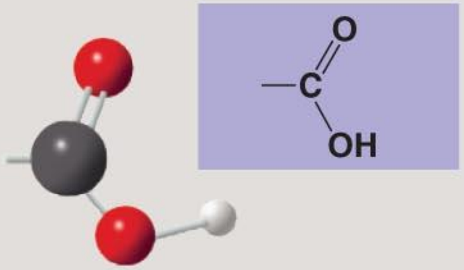
- A ketone and an aldehyde may be structural isomers with different properties, as is the case for acetone and propanal.
- These two groups are also found in sugars, giving rise to two major groups of sugars: aldoses (containing an aldehyde) and ketoses (containing a ketone).

Fig. 4-10c

Carboxyl group

Carboxyl

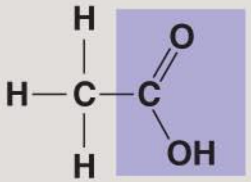
STRUCTURE



NAME OF COMPOUND

Carboxylic acids, or organic acids

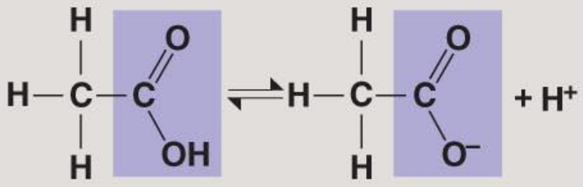
EXAMPLE



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,



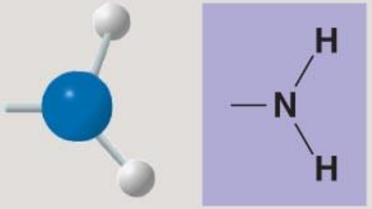
Acetic acid   Acetate ion

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

Amino group

Amino

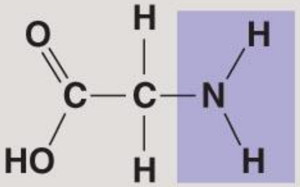
STRUCTURE



NAME OF COMPOUND

Amines

EXAMPLE

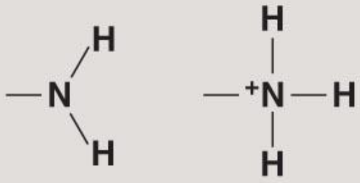


Glycine

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).



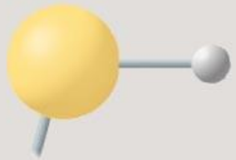
(nonionized) (ionized)

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

Sulfhydryl group

Sulfhydryl

STRUCTURE



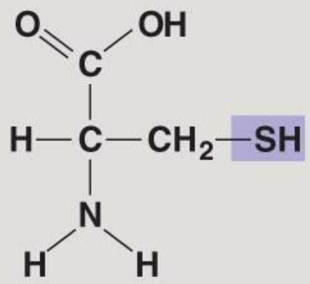
—SH

(may be written HS—)

NAME OF COMPOUND

Thiols

EXAMPLE



Cysteine

Cysteine is an important sulfur-containing amino acid.

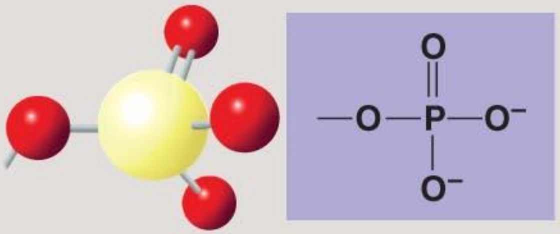
FUNCTIONAL PROPERTIES

- 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.

Phosphate group

Phosphate

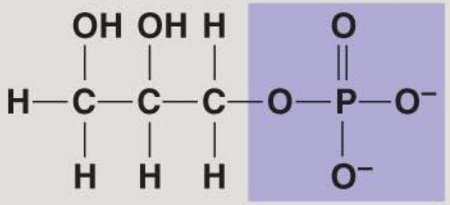
STRUCTURE



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.

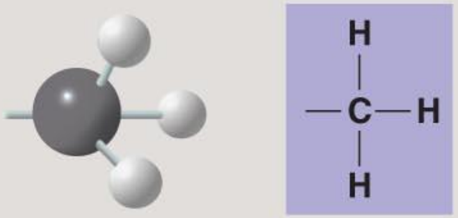
FUNCTIONAL PROPERTIES

- 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.

Methyl group

Methyl

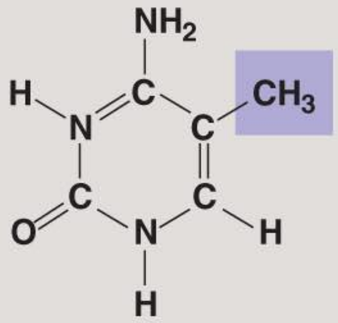
STRUCTURE



Methylated compounds

NAME OF COMPOUND

EXAMPLE



5-Methyl cytidine

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

- 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.

FUNCTIONAL PROPERTIES

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-UN2

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

Fig. 4-UN3

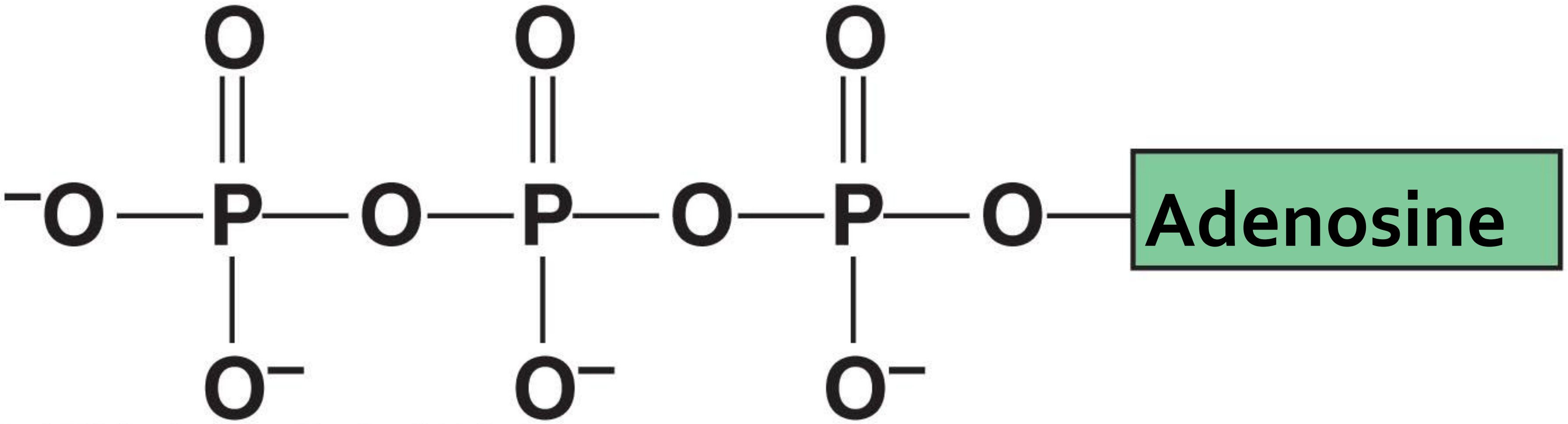


Fig. 4-UN4

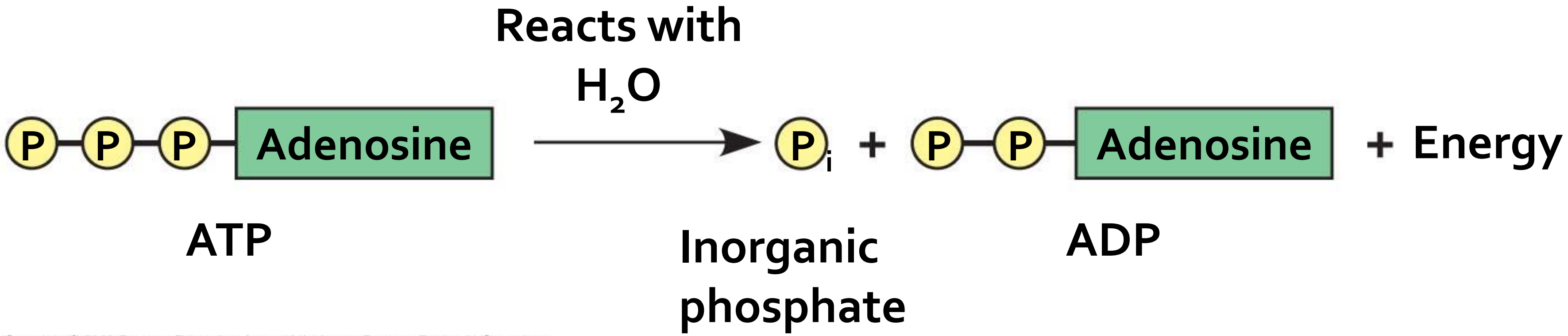

Reacts with
H_2O
P
P
P
Adenosine
ATP
P_i
+
P
P
Adenosine
+ Energy
Inorganic
phosphate
ADP

Fig. 4-UN5

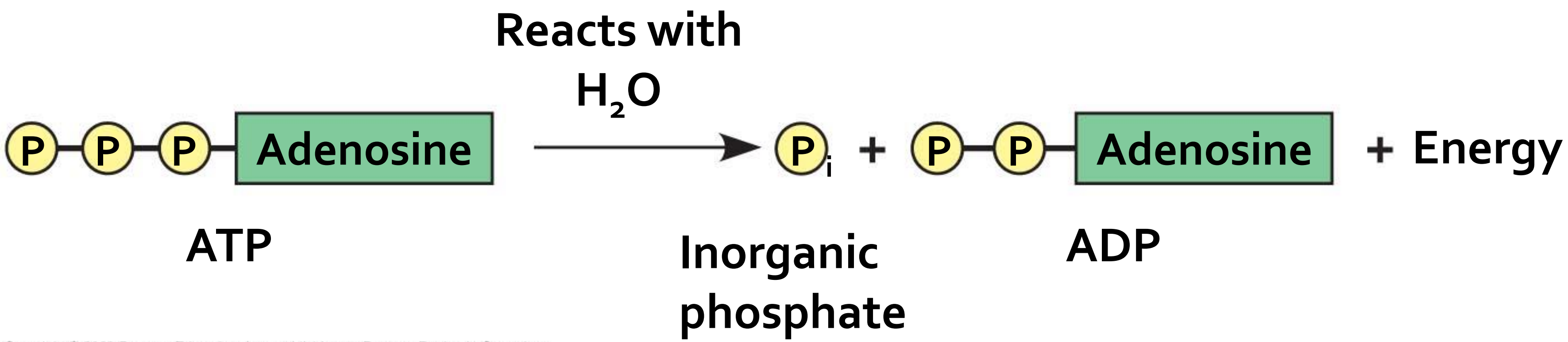

Reacts with H_2O
P P P Adenosine
ATP
P_i + P P Adenosine + Energy
Inorganic phosphate
ADP

Fig. 4-UN6

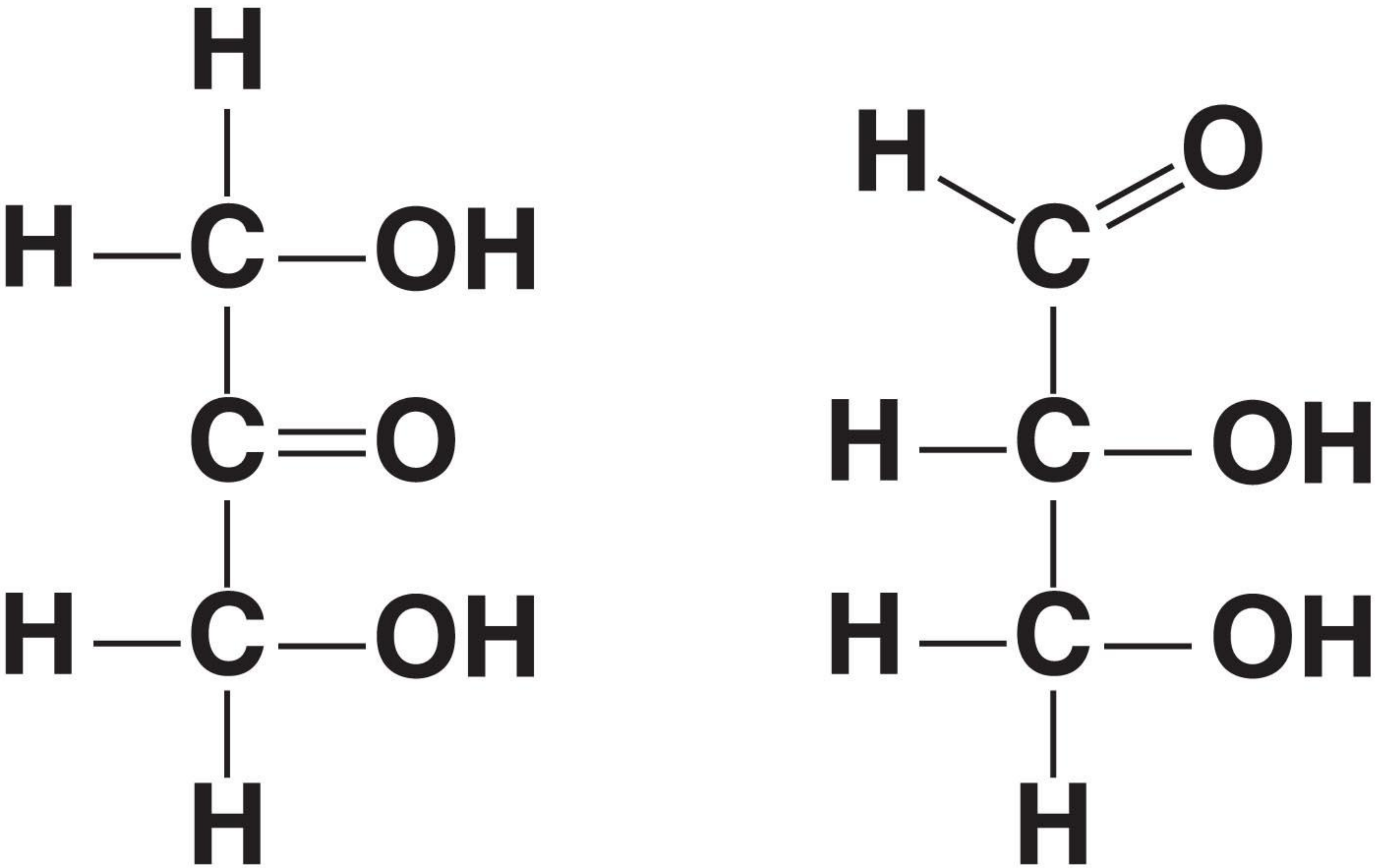


Fig. 4-UN7

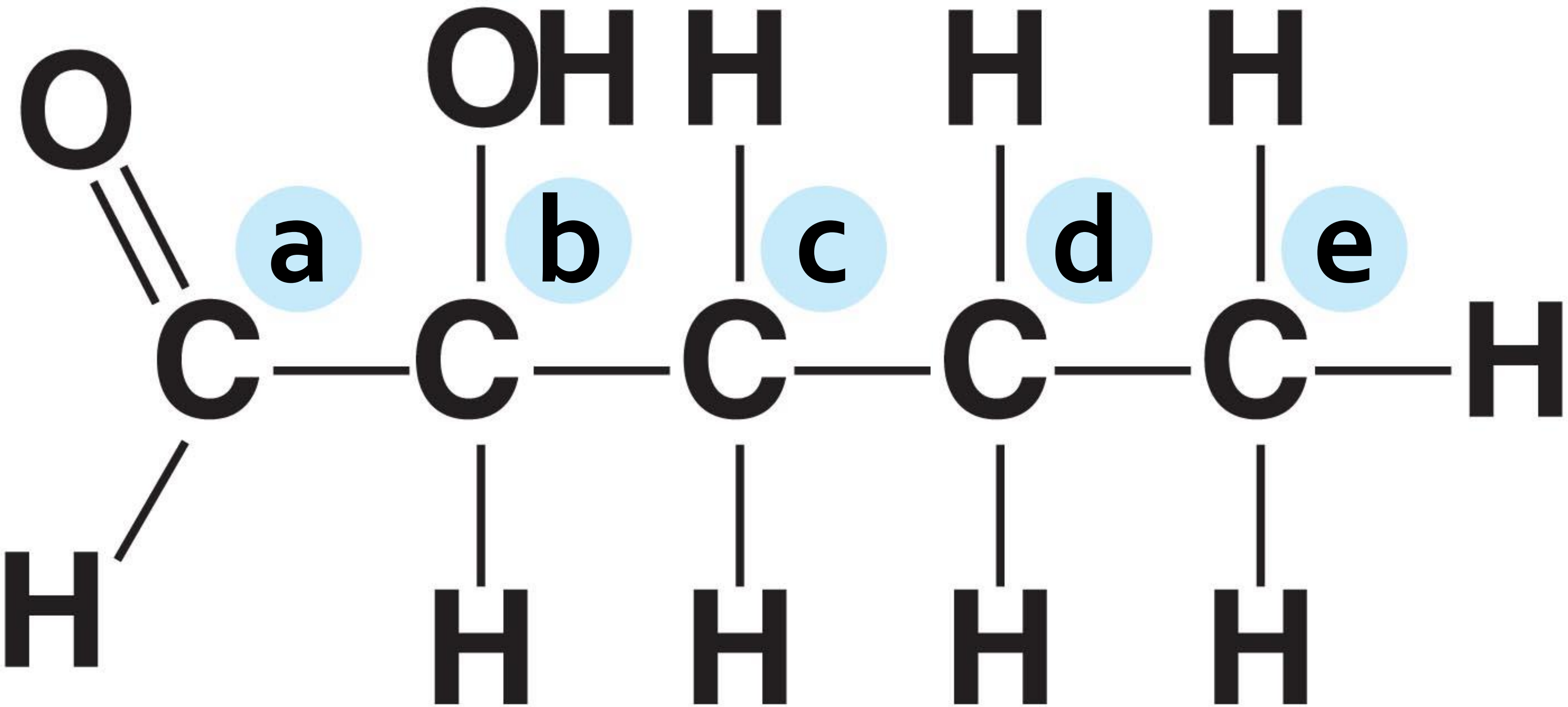


Fig. 4-UN8

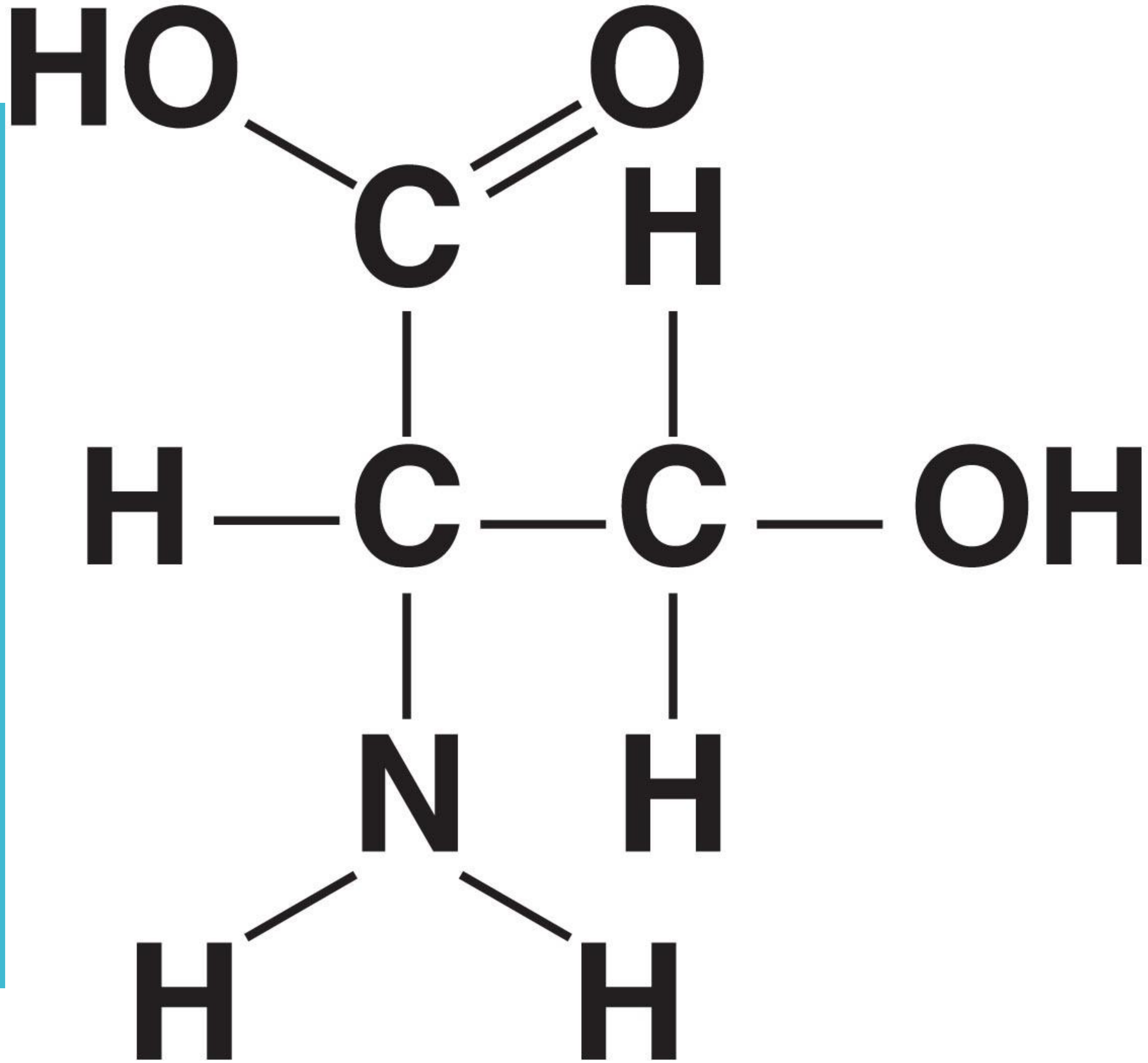
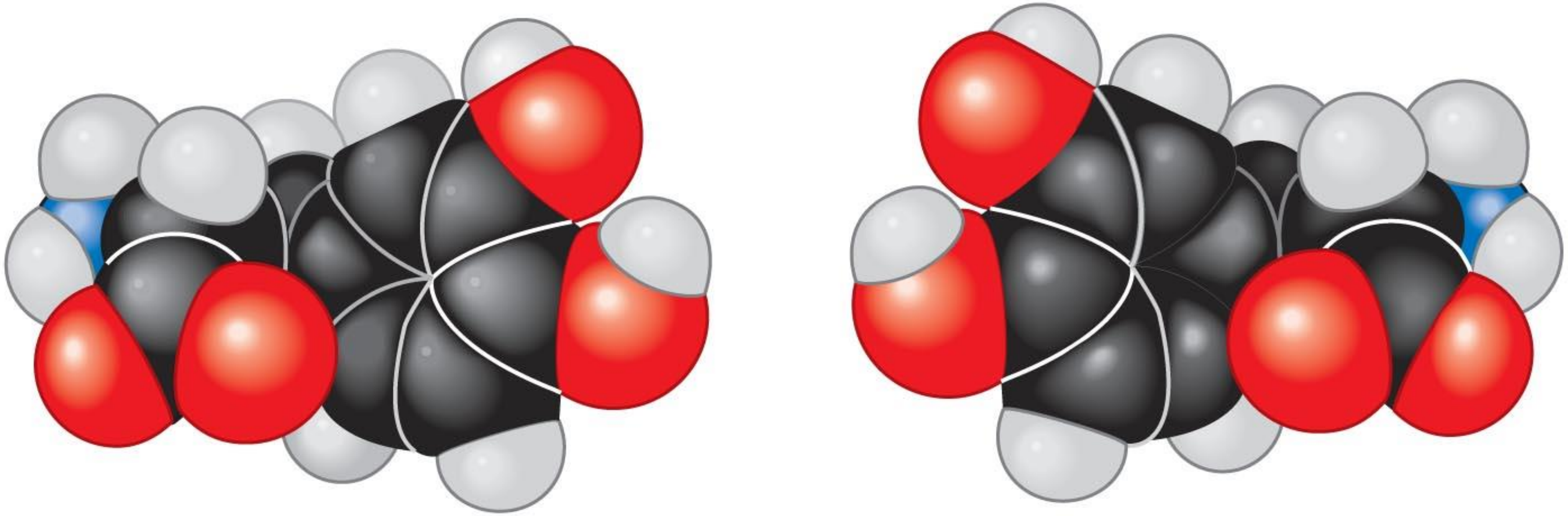


Fig. 4-UN9



L-dopa D-dopa

Fig. 4-UN10

Fig. 4-UN11

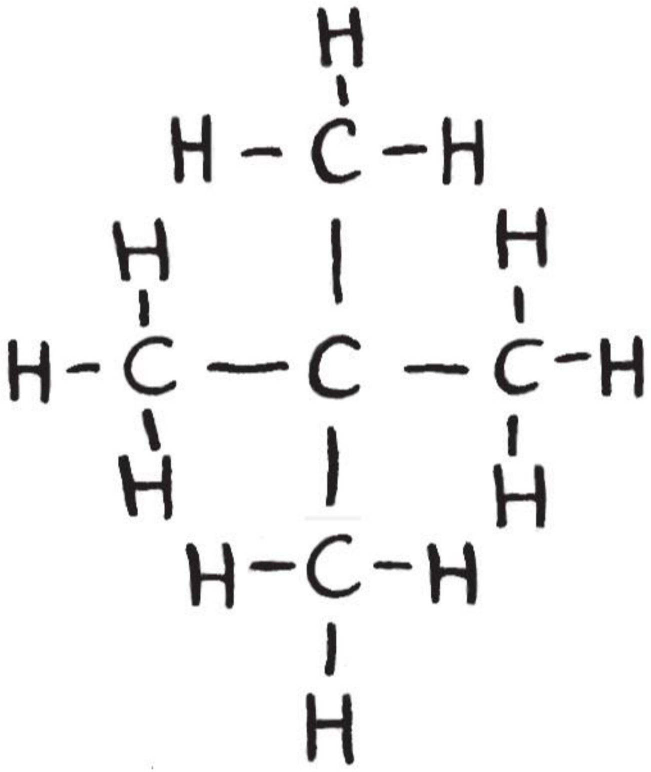


Fig. 4-UN12

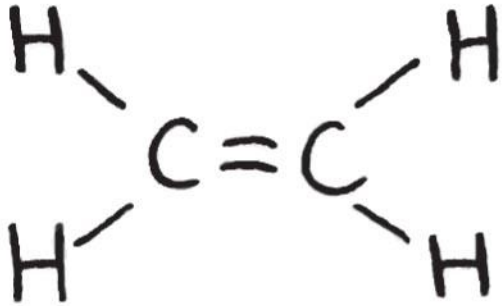
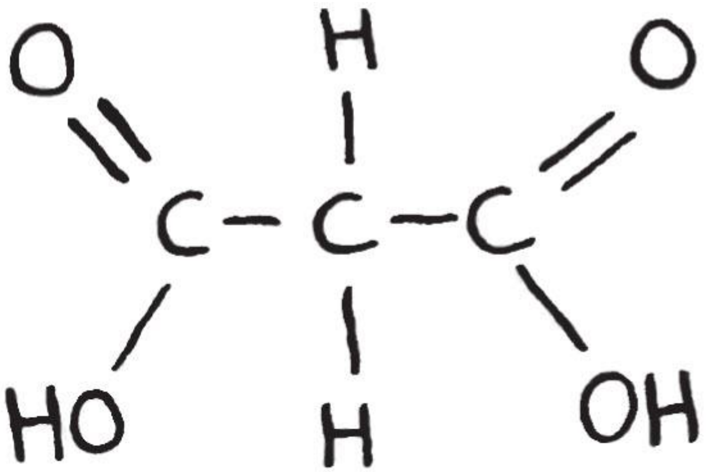


Fig. 4-UN13



Explain how carbon’s electron configuration explains its ability to form large, complex, diverse organic molecules

Describe how carbon skeletons may vary and explain how this variation contributes to the diversity and complexity of organic molecules

Distinguish among the three types of isomers: structural, geometric, and enantiomer

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

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