CHEMISTRY AND THE MOLECULAR DIVERSITY OF LIFE

YM-9-25-2003

A mole is X grams of a substance, where X is its relative molecular mass (molecular weight). A mole will contain 6×10^{23} molecules of the substance.

1 mole of carbon weighs 12 g
1 mole of glucose weighs 180 g
1 mole of sodium chloride weighs 58 g

Molar solutions have a concentration of 1 mole of the substance in 1 liter of solution. A molar solution (denoted as 1 M) of glucose, for example, has 180 g/l, while a millimolar solution (1mM) has 180 mg/l.

The standard abbreviation for gram is g; the abbreviation for liter is l.

Figure 2–2. Molecular Biology of the Cell, 4th Edition.

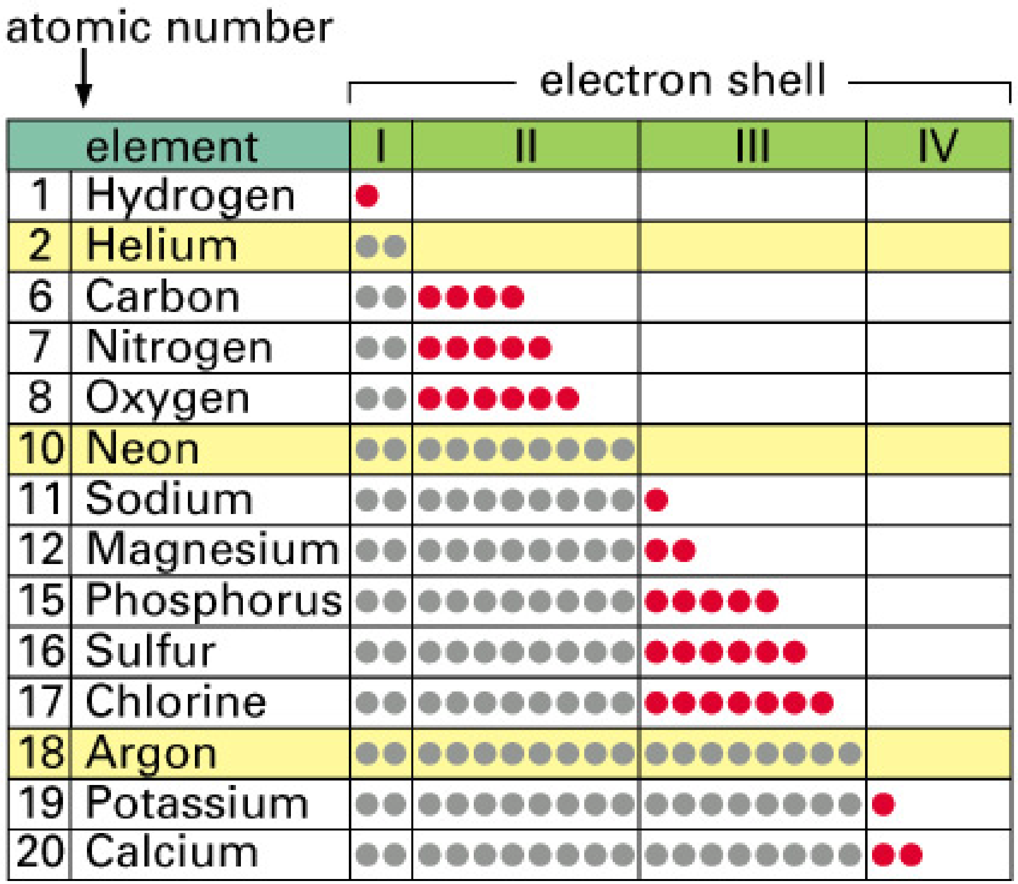
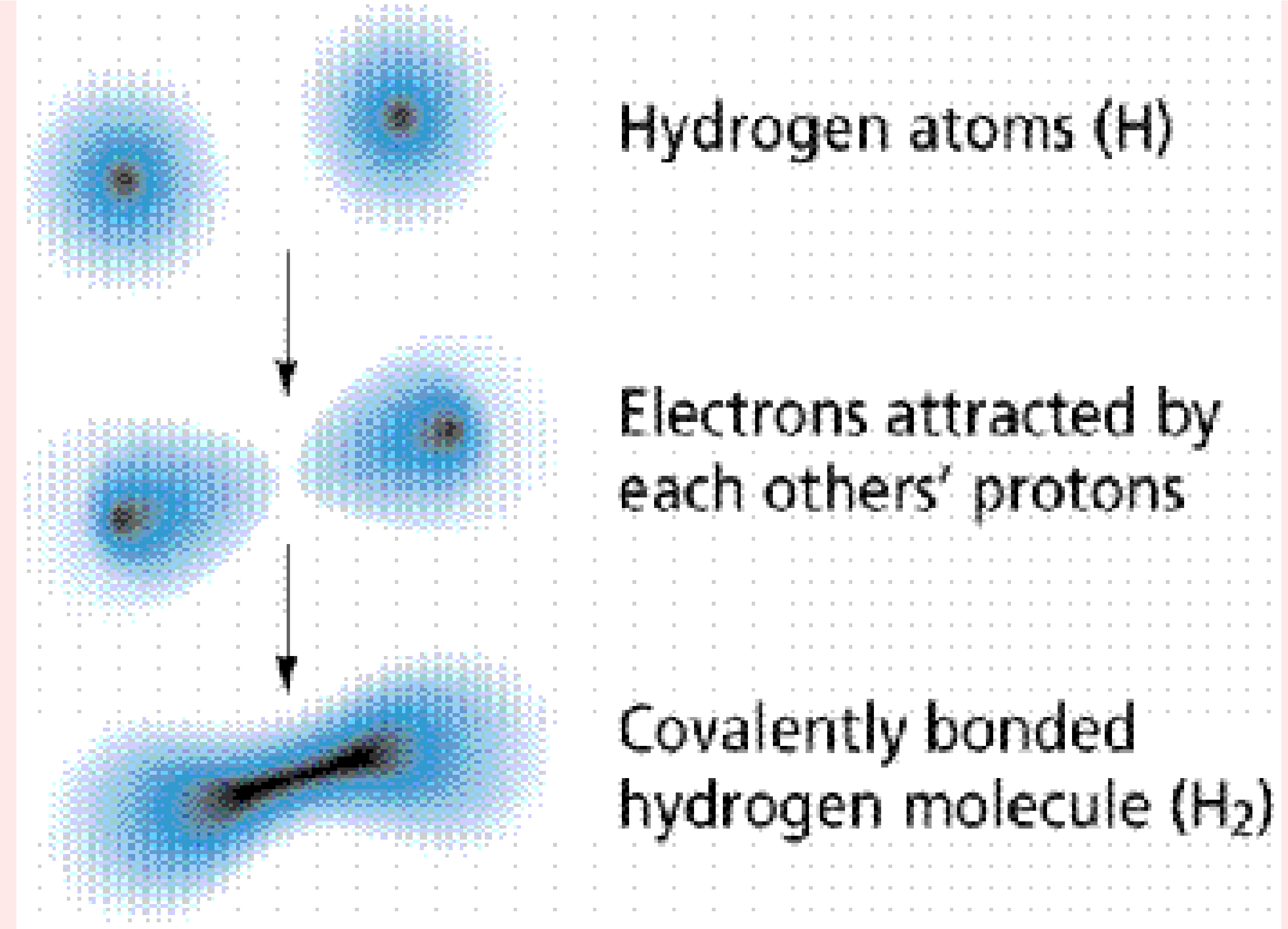


Figure 2–4. Molecular Biology of the Cell, 4th Edition.

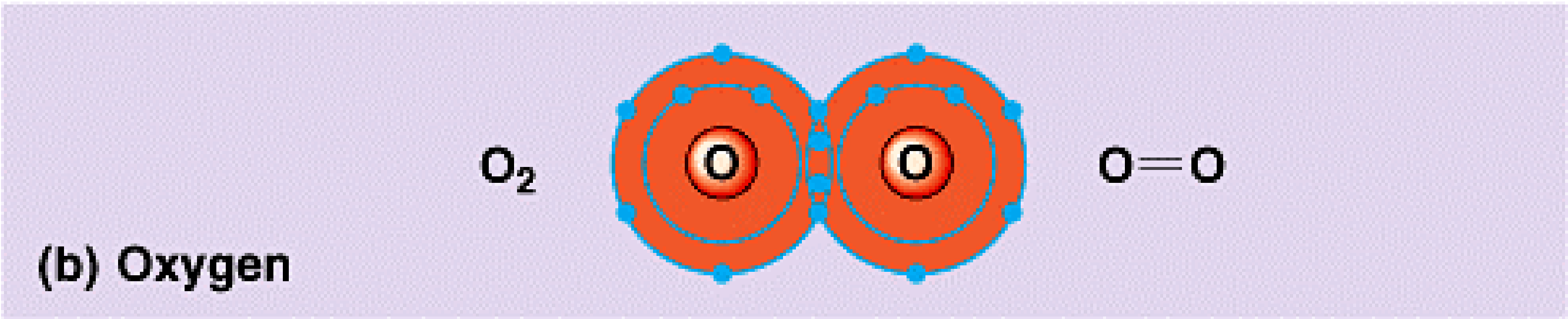
chemical bonds

- Atoms with incomplete valence shells interact by either sharing or transferring valence electrons with other atoms.
- Covalent bond共價鍵
- Ionic bond離子鍵
- Hydrogen bond氫鍵
- Hydrophobic interaction厭水性結合



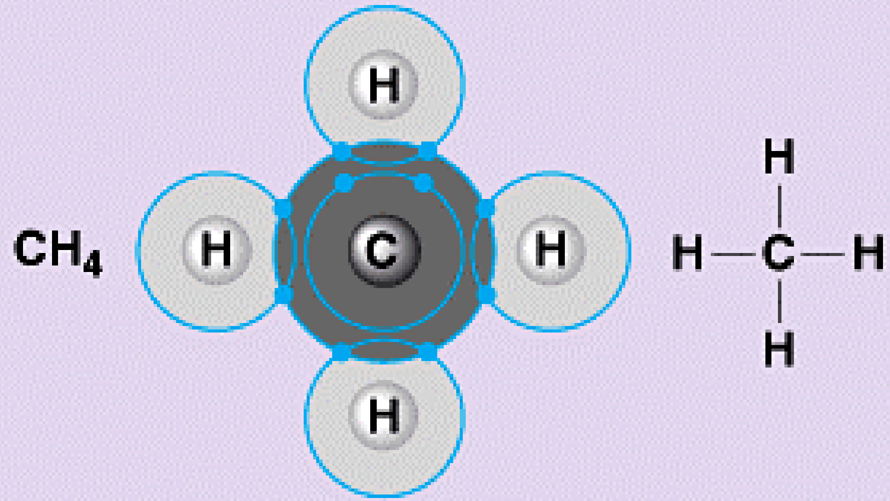
兩個氫原子之間共價鍵的形成

- Oxygen needs to add 2 electrons to the ***6*** already present to complete its valence shell.
  - Two oxygen atoms can form a molecule by sharing *two* pairs of valence electrons.
  - These atoms have formed a **double covalent bond**.



(b) Oxygen

– Methane, CH_4, satisfies the valences of both C and H.



(d) Methane

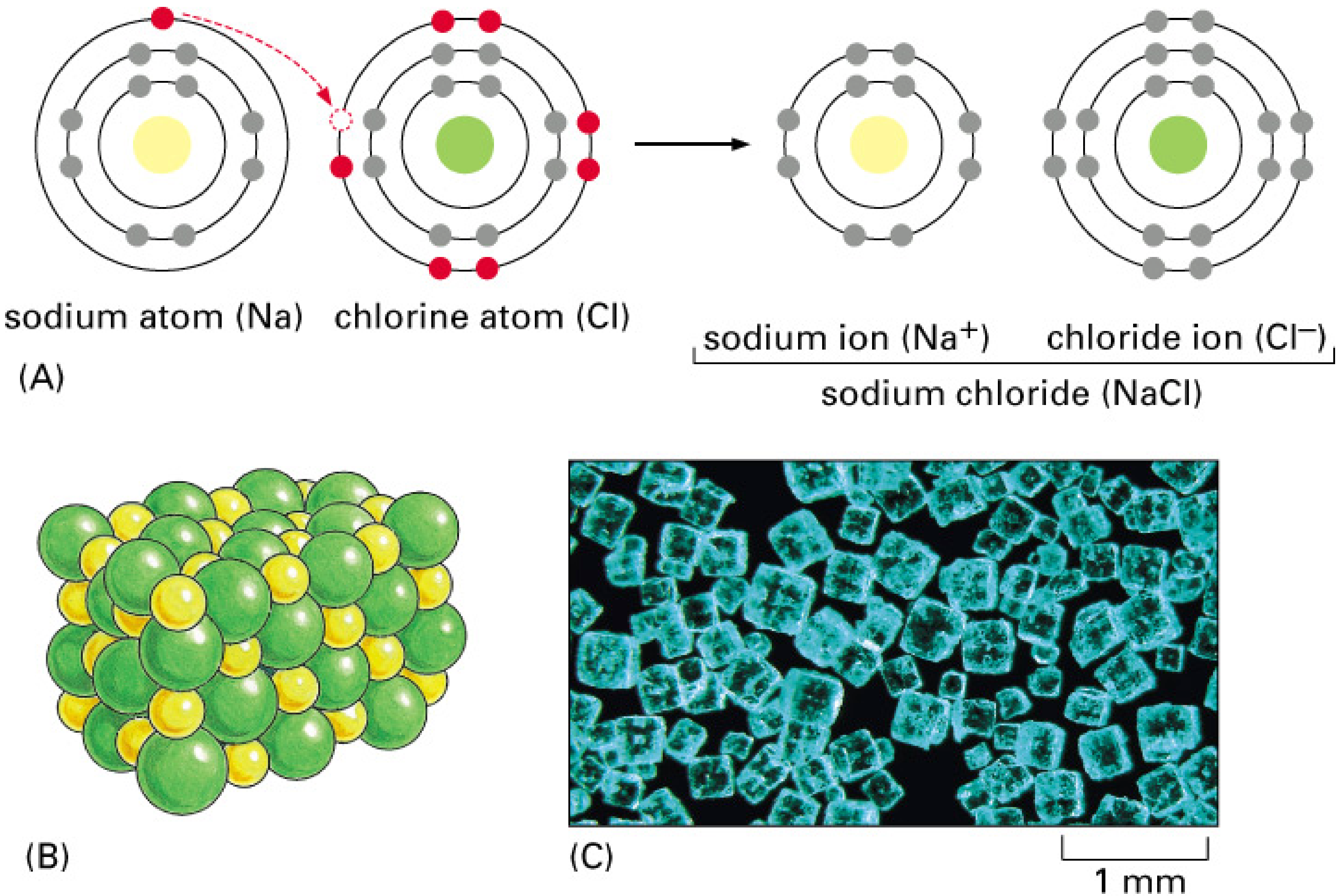


Figure 2–6. Molecular Biology of the Cell, 4th Edition.

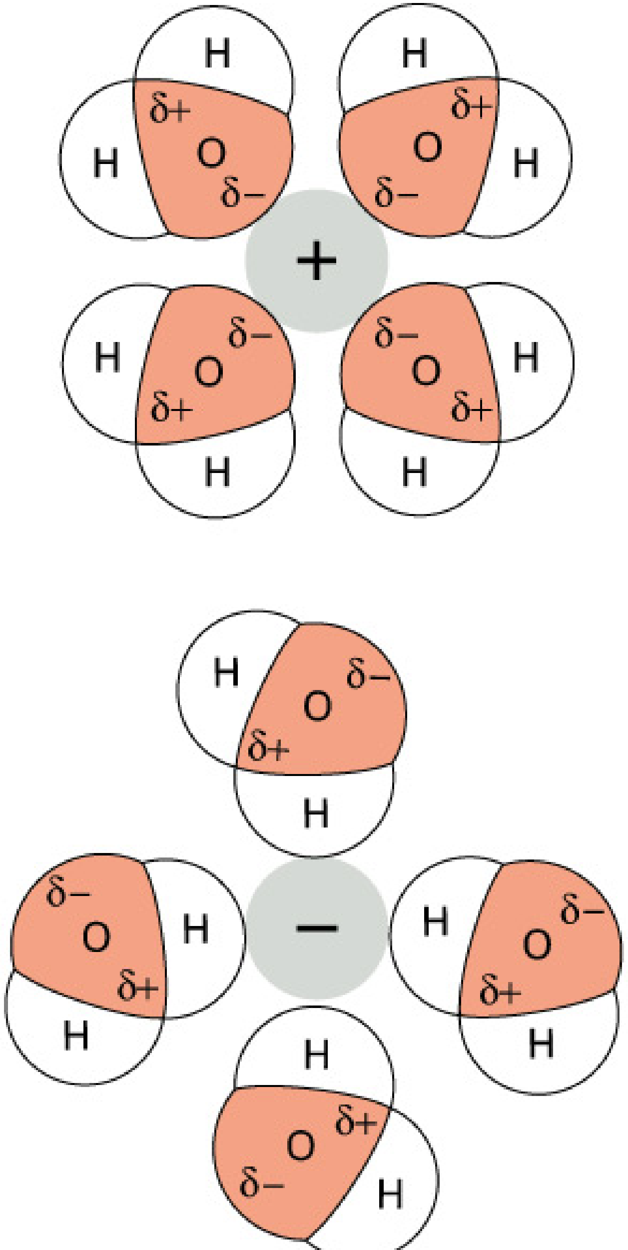
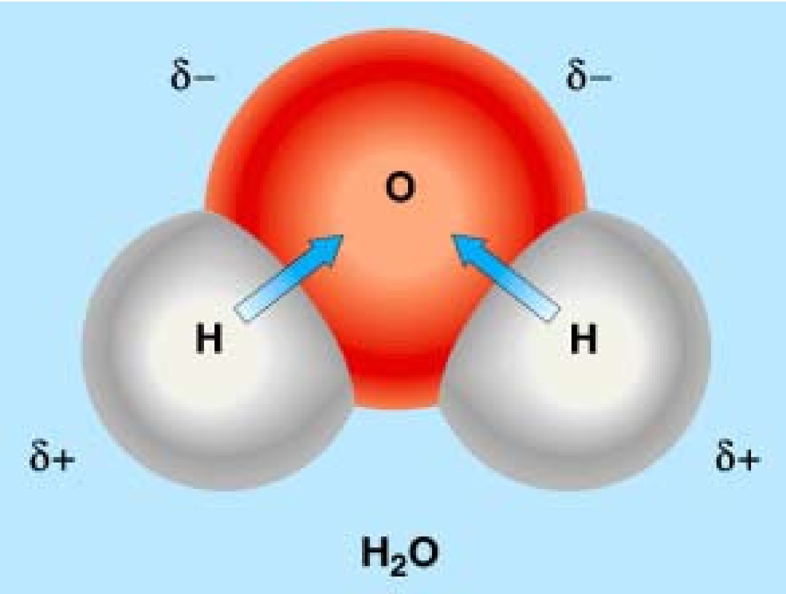
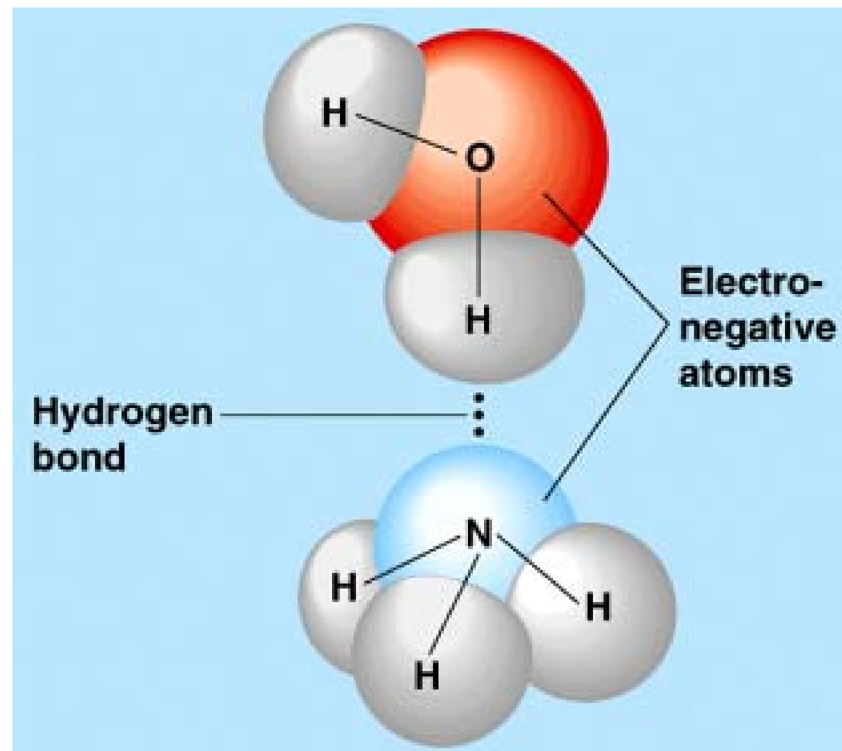


Figure 2–14. Molecular Biology of the Cell, 4th Edition.

- The attraction of an atom for the electrons of a covalent bond is called its **electronegativity**陰電性.
- Strongly electronegative atoms attempt to pull the shared electrons toward themselves.
- The bonds between oxygen and hydrogen in water are polar covalent because oxygen has a much higher electronegativity than does hydrogen.



- Ammonia molecules and water molecules link together with weak ***hydrogen bonds***.
  - In the ammonia molecule, the hydrogen atoms have partial positive charges and the more electronegative nitrogen atom has a partial positive charge.
  - In the water molecule, the hydrogen atoms also have partial positive charges and the oxygen atom partial negative charges.
  - Areas with opposite charges are attracted.



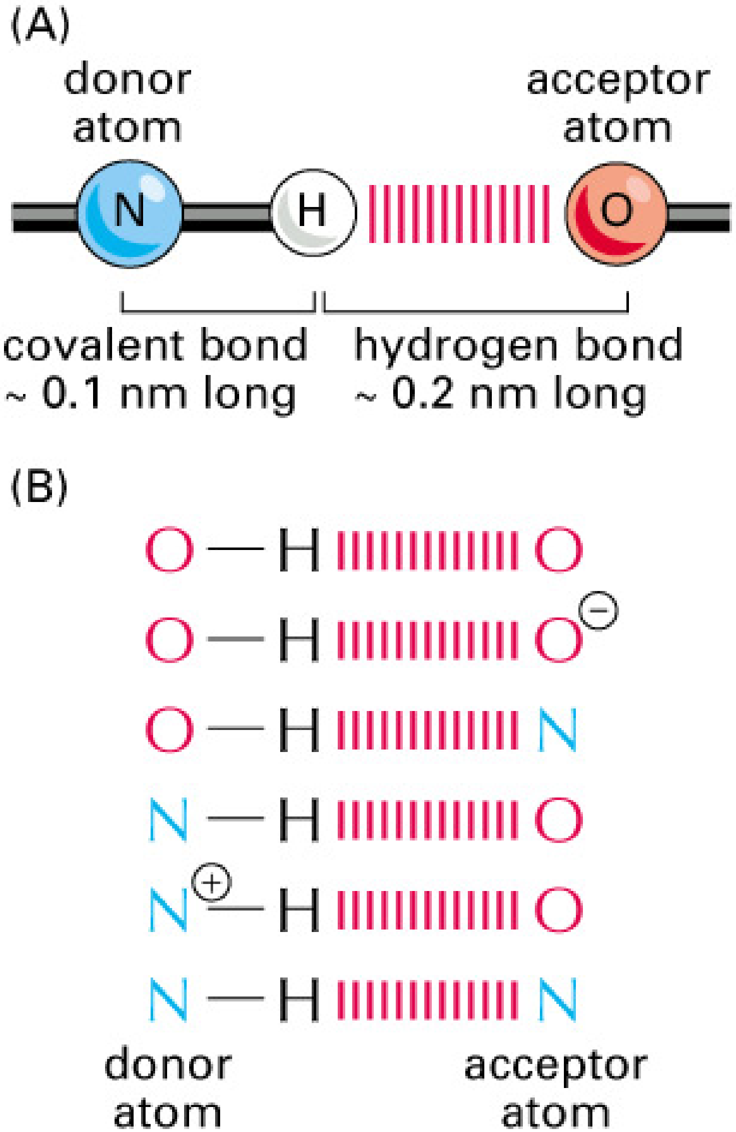


Figure 2–15. Molecular Biology of the Cell, 4th Edition.

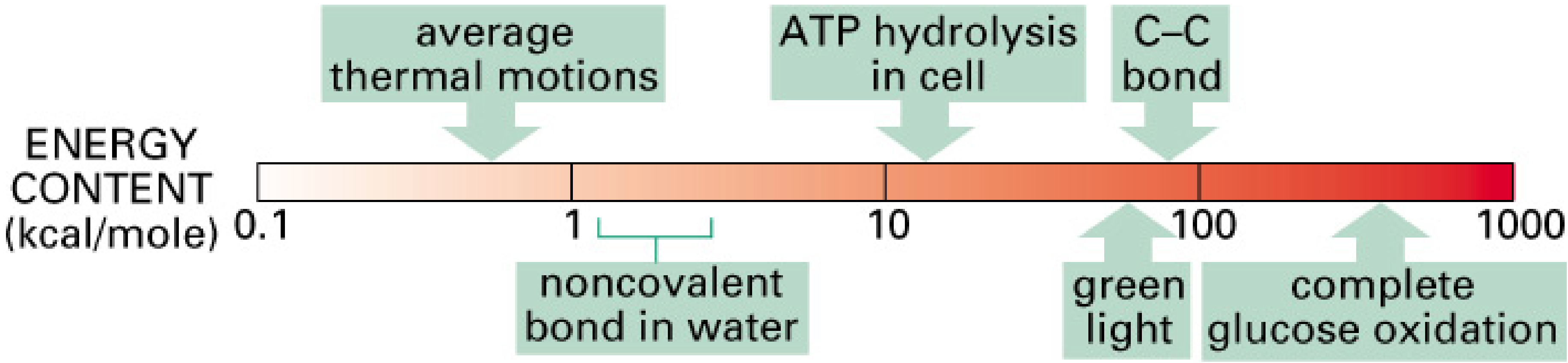
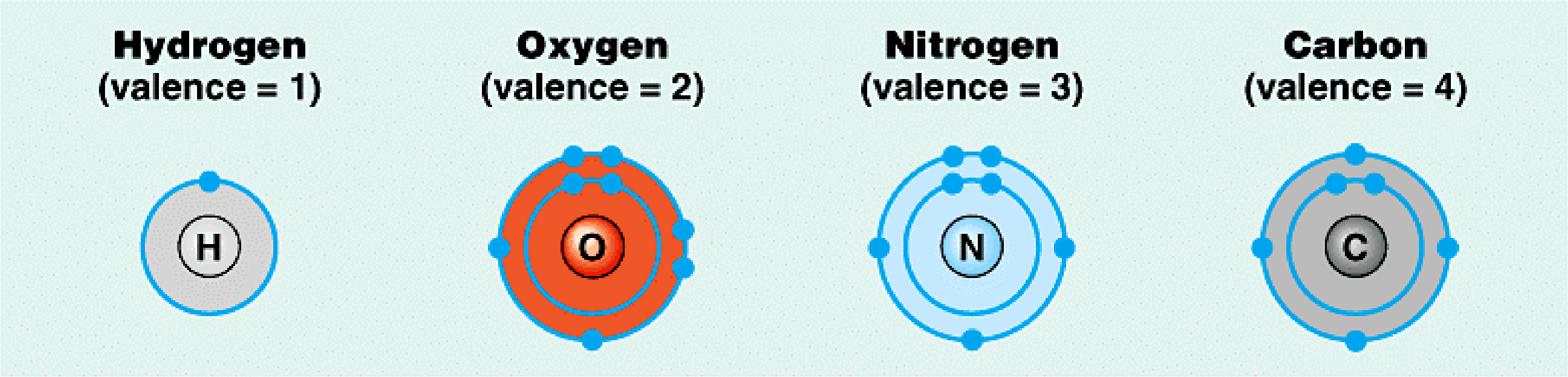


Figure 2–7. Molecular Biology of the Cell, 4th Edition.

- The electron configuration of carbon gives it compatibility to form covalent bonds with many different elements.
- The valences of carbon and its partners can be viewed as the building code that governs the architecture of organic molecules.



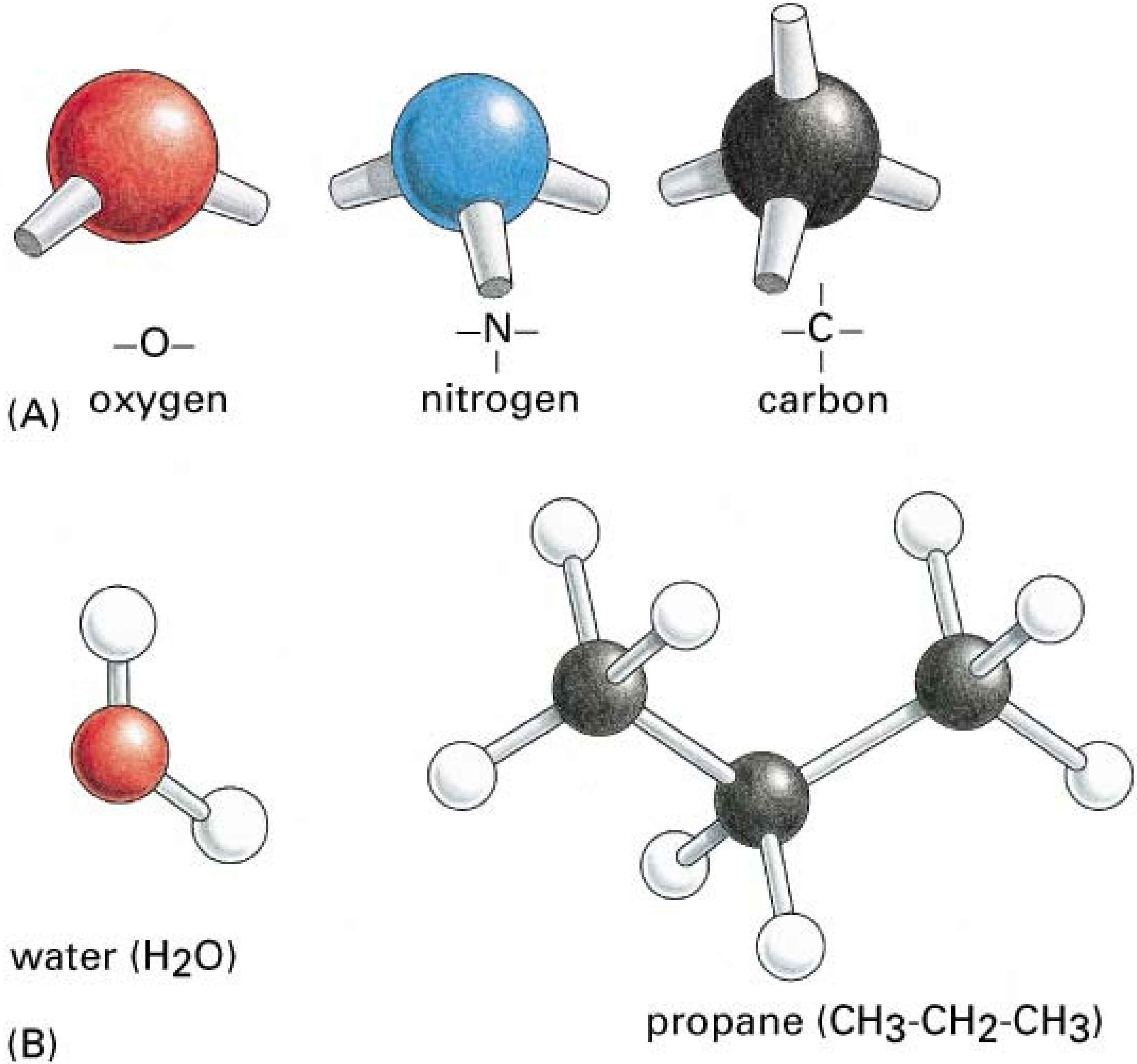
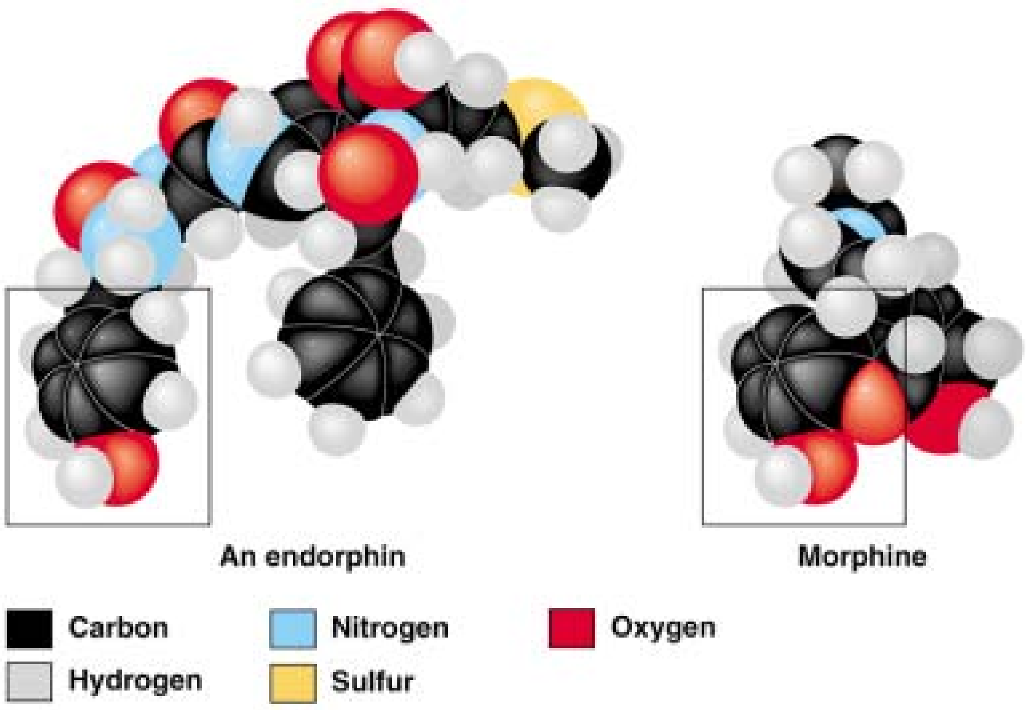


Figure 2–8. Molecular Biology of the Cell, 4th Edition.

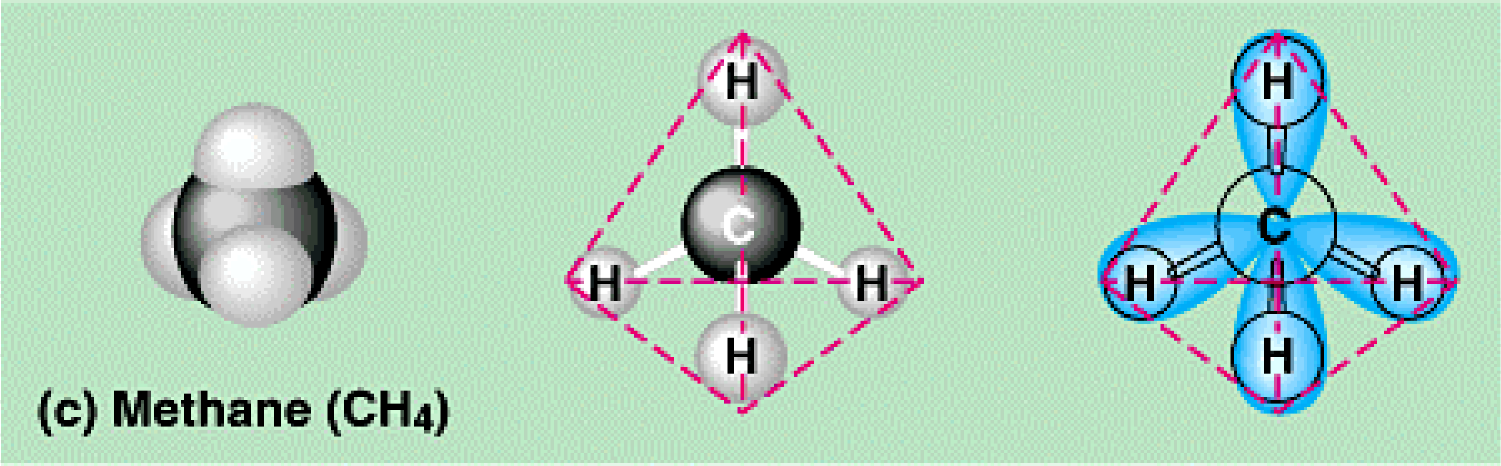
- Molecules with similar shapes can interact in similar ways.
  - For example, morphine, heroin, and other opiate drugs are similar enough in shape that they can bind to the same receptors as natural signal molecules, called endorphins.
  - Binding to the receptors produces euphoria and relieves pain.



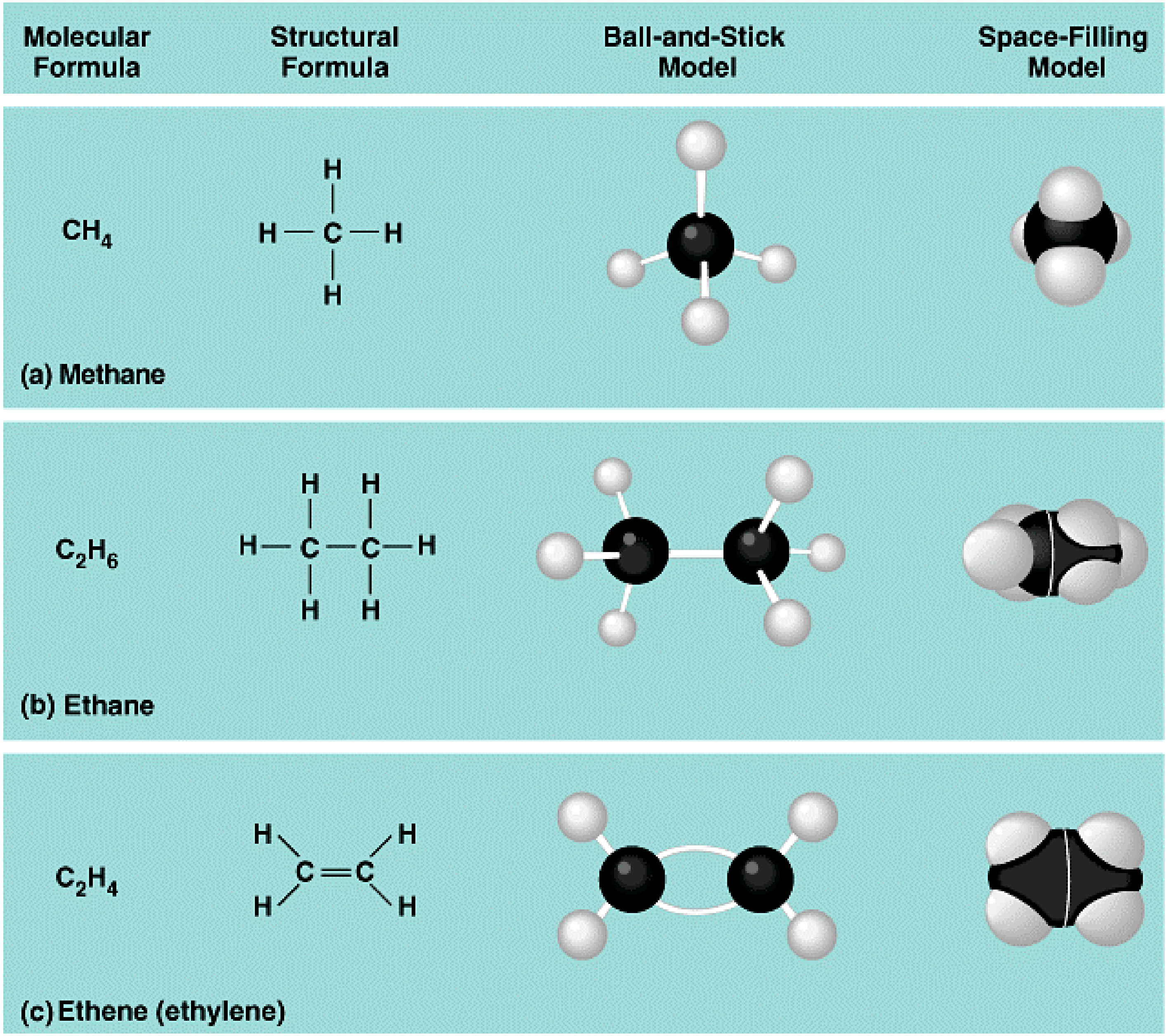
Organic chemistry is the study of carbon compounds

- The study of carbon compounds, **organic chemistry,** focuses on any compound with carbon (organic compounds).
  - While the name, organic compounds, implies that these compounds can only come from biological processes, they can be synthesized by non-living reactions.
  - Organic compounds can range from the simple (CO_2 or CH_4) to complex molecules, like proteins, that may weigh over 100,000 daltons.

- A methane molecule (CH_4) has all four hybrid orbitals shared and has hydrogen nuclei at the corners of the tetrahedron.
- In larger molecules the tetrahedral shape of carbon bonded to four other atoms is often a repeating motif.



(c) Methane (CH_4)


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

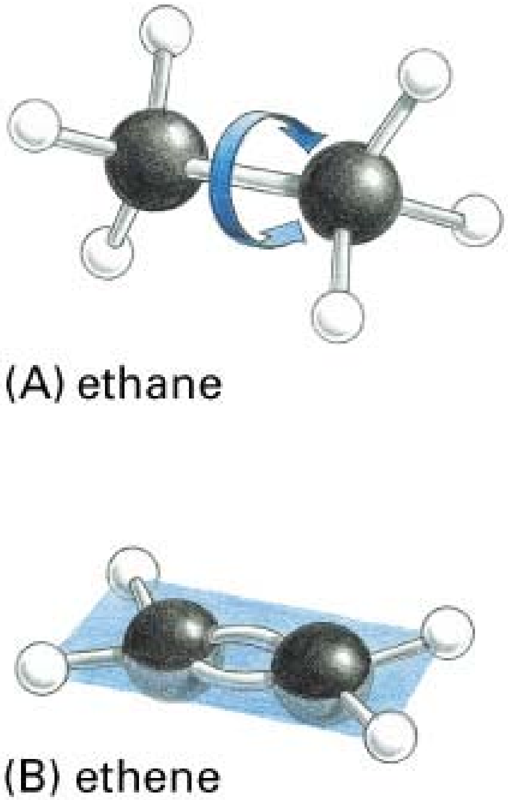
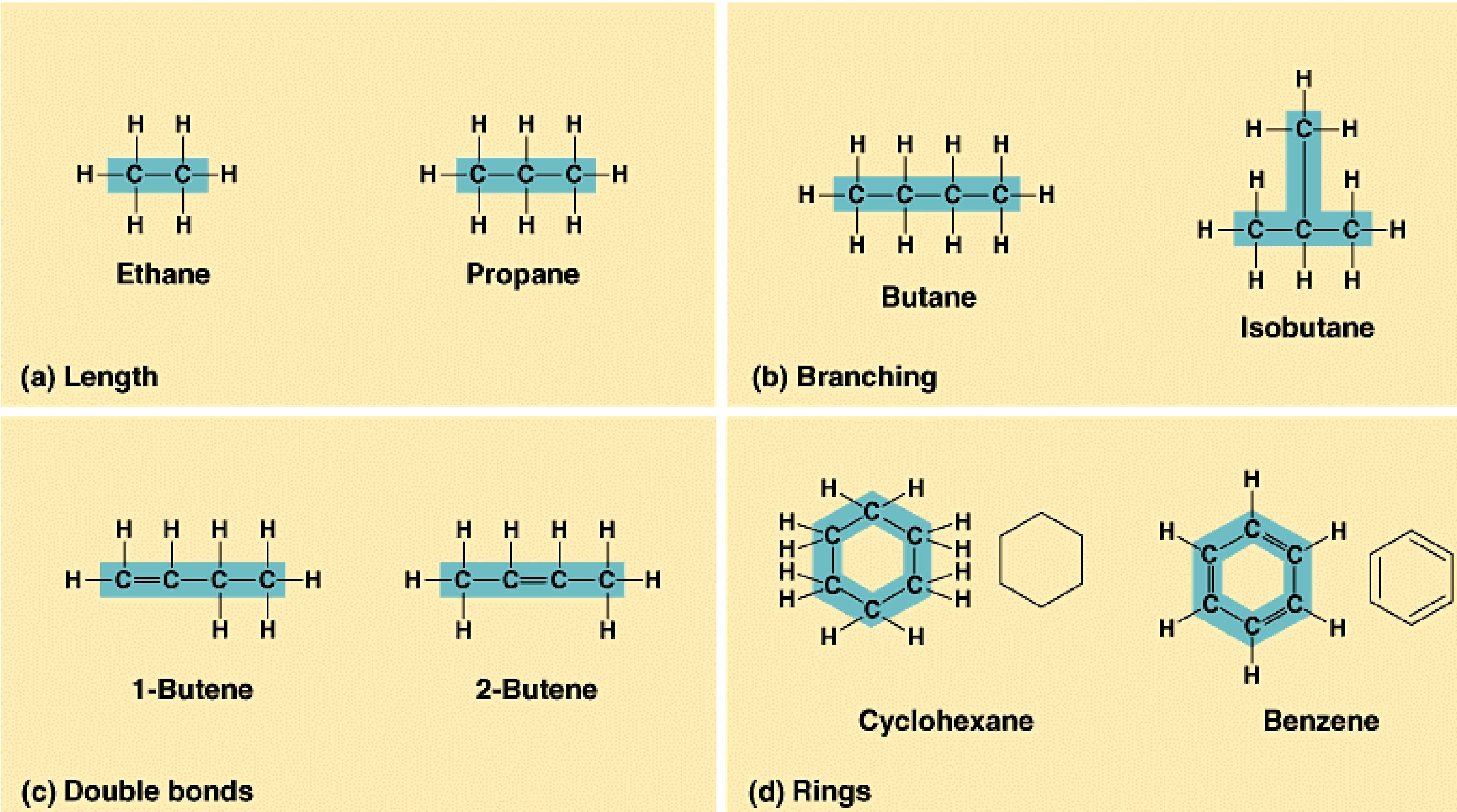
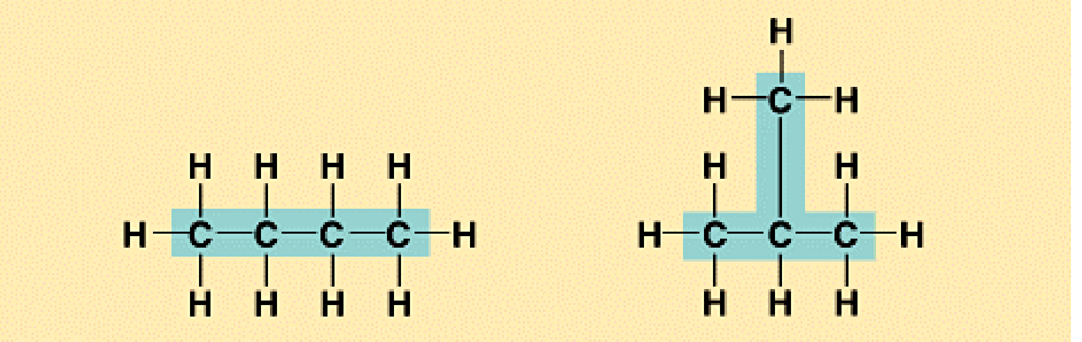


Figure 2–9. Molecular Biology of the Cell, 4th Edition.


Ethane
Propane
(a) Length
Butane
Isobutane
(b) Branching
1-Butene
2-Butene
(c) Double bonds
Cyclohexane
Benzene
(d) Rings

- **Isomers** are compounds that have the same molecular formula but different structures and therefore different chemical properties.
  - For example, butane and isobutane have the same molecular formula C_4H_{10}, but butane has a straight skeleton and isobutane has a branched skeleton.
- The two butanes are **structural isomers**, molecules with the same molecular formula but differ in the covalent arrangement of atoms.

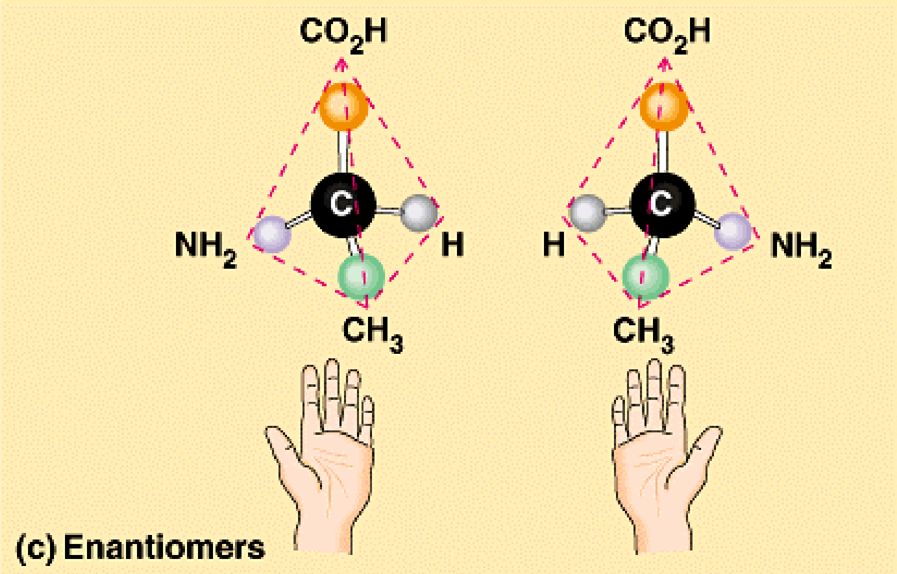


(a) Structural isomers

- **Geometric isomers** are compounds with the same covalent partnerships that differ in their spatial arrangement around a carbon-carbon double bond.
  - The double bond does not allow atoms to rotate freely around the bond axis.
  - The biochemistry of vision involves a light-induced change in the structure of rhodopsin in the retina from one geometric isomer to another.

(b) Geometric isomers

- **Enantiomers** are molecules that are mirror images of each other
  - Enantiomers are possible if there are <u>four</u> <u>different</u> atoms or groups of atoms bonded to a carbon.
  - If this is true, it is possible to arrange the four groups in space in two different ways that are mirror images.
  - They are like left-handed and right-handed versions.
  - Usually one is biologically active, the other inactive.



(c) Enantiomers

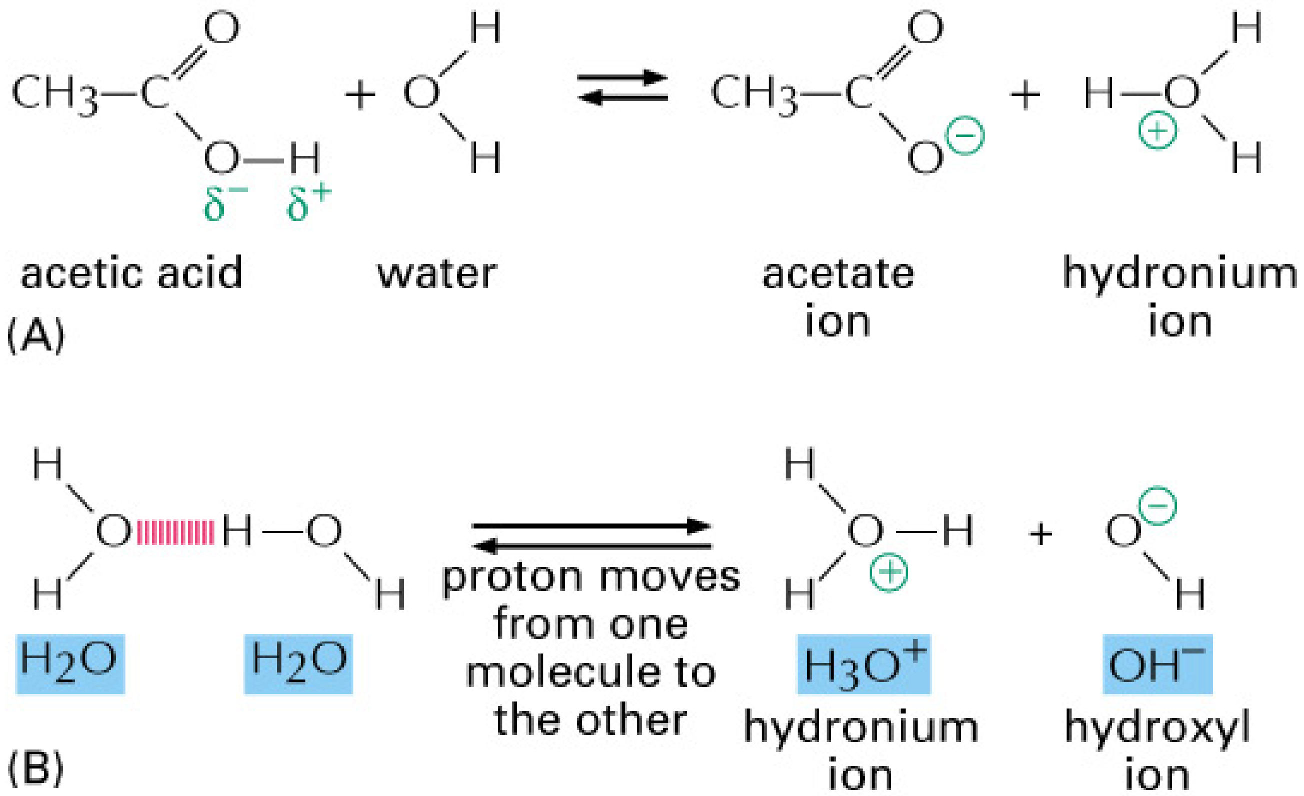


Figure 2–13. Molecular Biology of the Cell, 4th Edition.

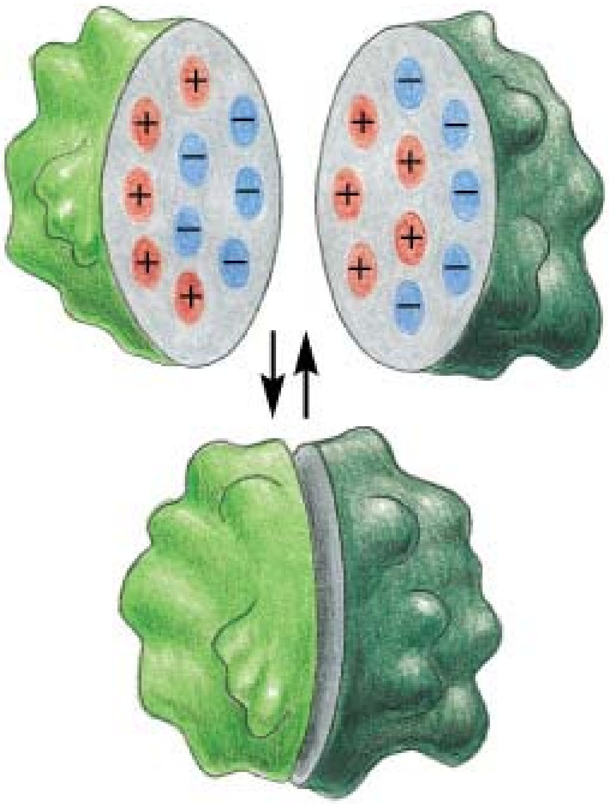


Figure 2–16. Molecular Biology of the Cell, 4th Edition.

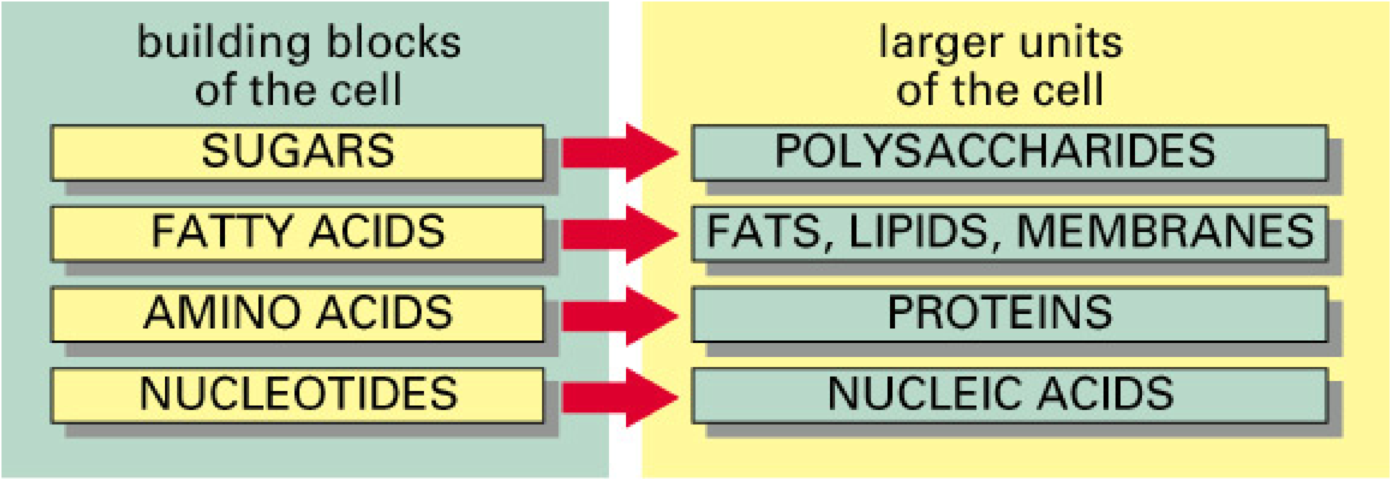


Figure 2–17. Molecular Biology of the Cell, 4th Edition.

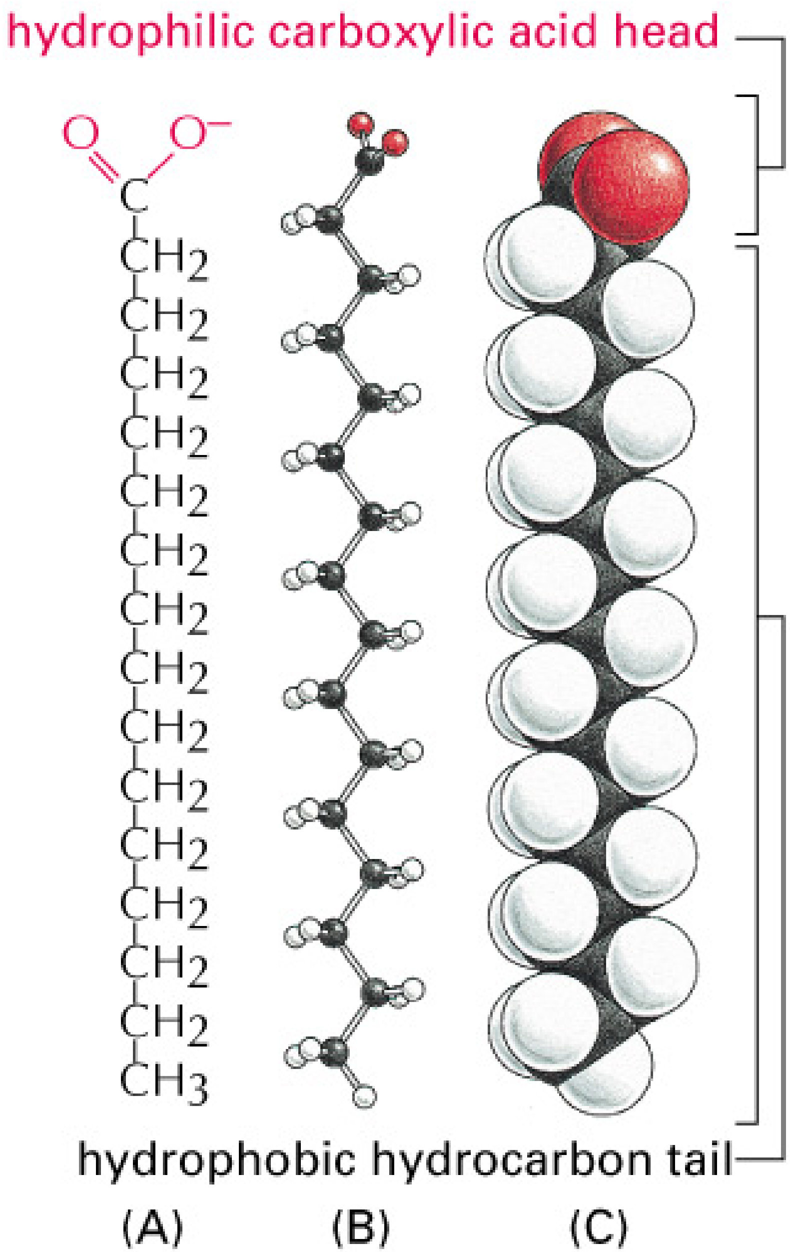


Figure 2–21. Molecular Biology of the Cell, 4th Edition.

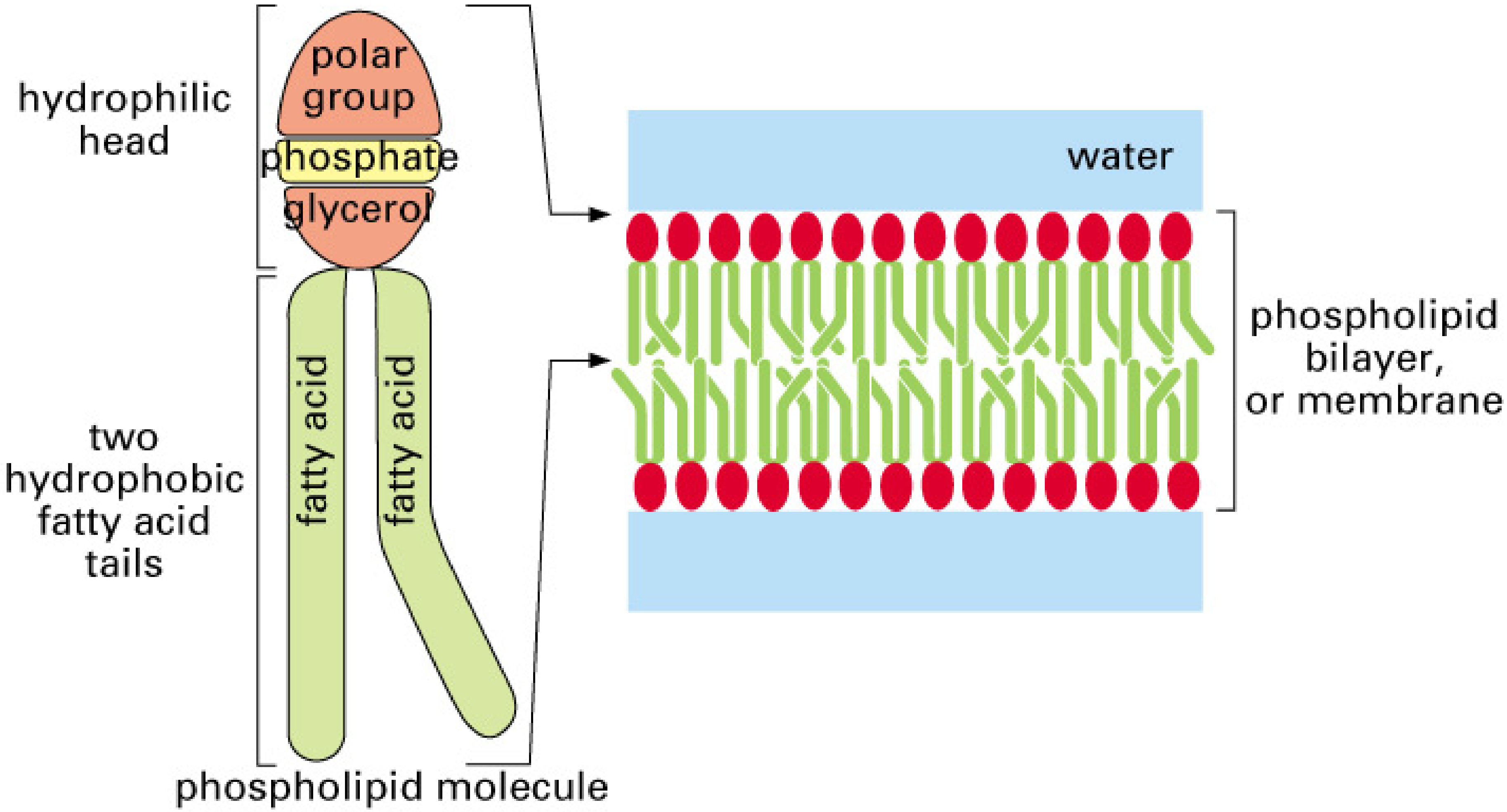
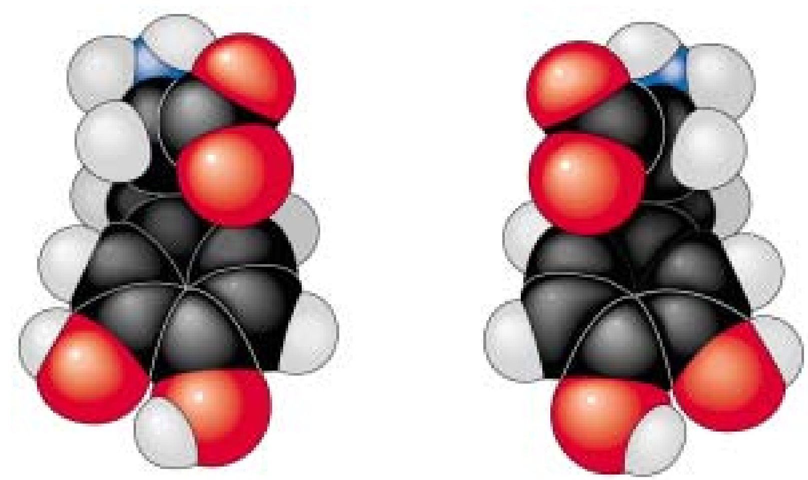


Figure 2–22. Molecular Biology of the Cell, 4th Edition.

- Even the subtle structural differences in two enantiomers have important functional significance because of emergent properties from the specific arrangements of atoms.
  - One enantiomer of the drug thalidomide reduced morning sickness, its desired effect, but the other isomer caused severe birth defects.
  - The L-Dopa isomer is an effective treatment of Parkinson's disease, but the D-Dopa isomer is inactive.



L-Dopa (effective against Parkinson's disease)

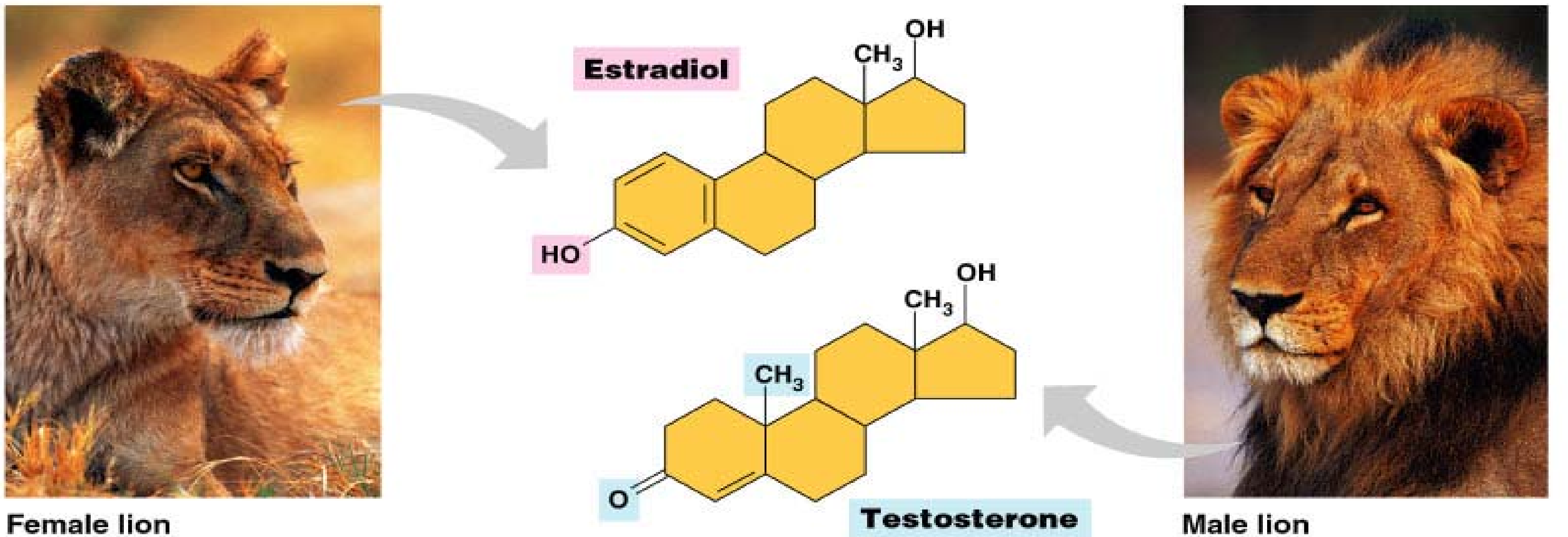
D-Dopa (biologically inactive)

Fig. 4.7

Functional groups contribute to the molecular diversity of life

- The components of organic molecules that are most commonly involved in chemical reactions are known as **functional groups**.
  - Functional groups are attachments that replace one or more hydrogen atoms to the carbon skeleton of the hydrocarbon.
- Each functional groups behaves consistently from one organic molecule to another.
- The number and arrangement of functional groups help give each molecule its unique properties.

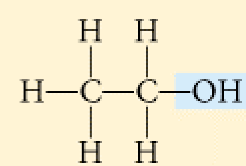
- The basic structure of testosterone (male hormone) and estradiol (female hormone) is identical.
    - Both are steroids with four fused carbon rings, but they differ in the functional groups attached to the rings.
  - These then interact with different targets in the body.



- There are six functional groups that are most important to the chemistry of life: hydroxyl, carbonyl, carboxyl, amino, sulfhydryl, and phosphate groups.
  - All are hydrophilic and increase solubility of organic compounds in water.

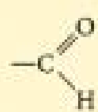
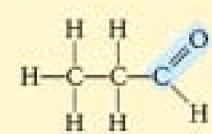
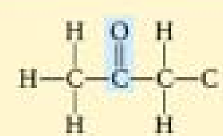
- In a **hydroxyl group** (-OH), a hydrogen atom forms a polar covalent bond with an oxygen which forms a polar covalent bond to the carbon skeleton.
  - Because of these polar covalent bonds hydroxyl groups improve the solubility of organic molecules.
  - Organic compounds with hydroxyl groups are **alcohols** and their names typically end in -*ol*.

Table 4.1 Functional Groups of Organic Compounds

Functional Group	Formula	Name of Compounds	Example
Hydroxyl	—OH	Alcohols	 Ethanol (the drug of alcoholic beverages)

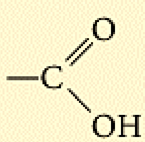
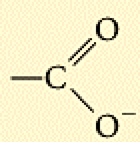
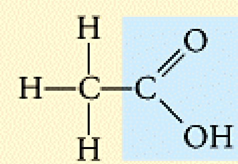
- A **carbonyl group** (=CO) consists of an oxygen atom joined to the carbon skeleton by a double bond.
  - If the carbonyl group is on the end of the skeleton, the compound is an **aldelhyde**.
  - If not, then the compound is a **ketone**.
  - Isomers with aldehydes versus ketones have different properties.

Table 4.1 Functional Groups of Organic Compounds

Functional Group	Formula	Name of Compounds	Example
Carbonyl		Aldehydes	 Propanal
		Ketones	 Acetone

- A **carboxyl group** (-COOH) consists of a carbon atom with a double bond with an oxygen atom and a single bond to a hydroxyl group.
  - Compounds with carboxyl groups are **carboxylic acids**.
  - A carboxyl group acts as an acid because the combined electronegativities of the two adjacent oxygen atoms increase the dissociation of hydrogen

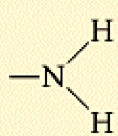
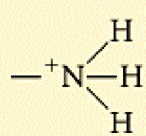
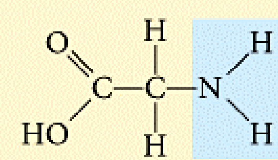
Table 4.1 Functional Groups of Organic Compounds

Functional Group	Formula	Name of Compounds	Example
Carboxyl	 (non-ionized)  (ionized)	Carboxylic acids	 Acetic acid* (the acid of vinegar)

*The ionized forms of the carboxyl and amino groups prevail in cells. However, acetic acid and glycine are represented here in their non-ionized forms.

- An **amino group** (-NH_2) consists of a nitrogen atom attached to two hydrogen atoms and the carbon skeleton.
  - Organic compounds with amino groups are **amines**.
  - The amino group acts as a base because ammonia can pick up a hydrogen ion (H^+) from the solution.
  - Amino acids, the building blocks of proteins, have amino and carboxyl groups.

Table 4.1 Functional Groups of Organic Compounds

Functional Group	Formula		Name of Compounds	Example
Amino	 (non-ionized)	 (ionized)	Amines	 Glycine* (an amino acid)

*The ionized forms of the carboxyl and amino groups prevail in cells. However, acetic acid and glycine are represented here in their non-ionized forms.