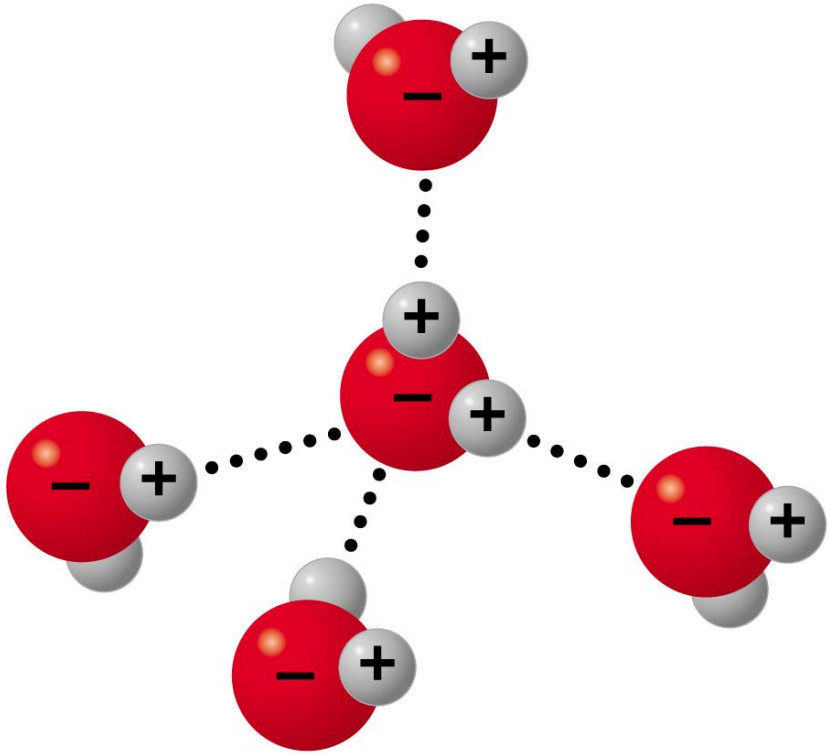


Chapter 2

Chemical Principles

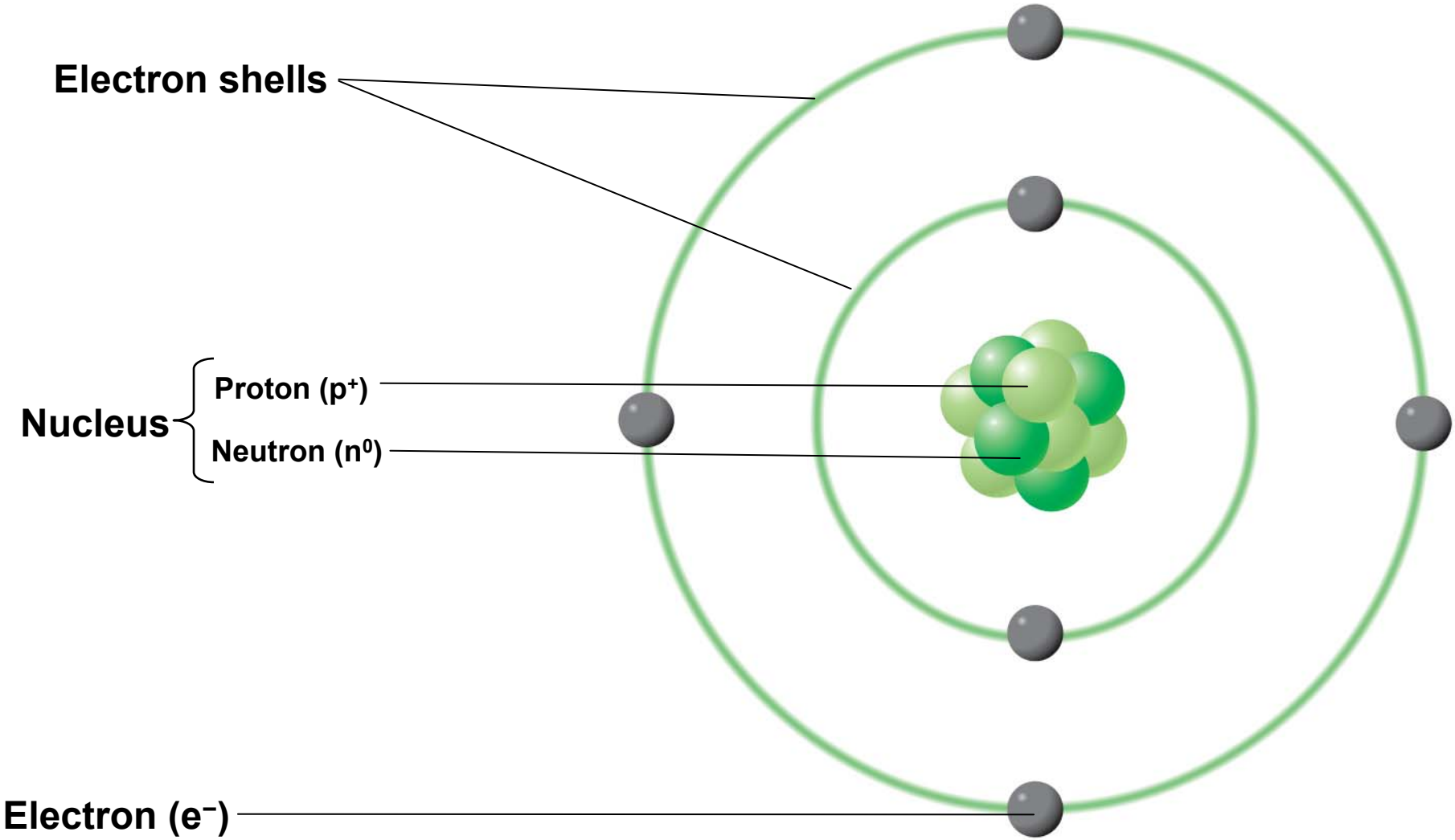
The Structure of Atoms

- **Chemistry** is the study of interactions between atoms and molecules
- The **atom** is the smallest unit of matter that enters into chemical reactions
- Atoms interact to form **molecules**

The Structure of Atoms

- Atoms are composed of
  - **Electrons**: negatively charged particles
  - **Protons**: positively charged particles
  - **Neutrons**: uncharged particles
- Protons and neutrons are in the nucleus
- Electrons move around the nucleus

The structure of an atom.



Chemical Elements

- Each chemical element has a different number of protons // atomic number defines element

- Isotopes of an element are atoms with different numbers of neutrons. Isotopes of oxygen:

$$^{16}_{8}O \qquad ^{17}_{8}O \qquad ^{18}_{8}O$$

TABLE 2.1 The Elements of Life*

Element	Symbol	Atomic Number	Approximate Atomic Weight
Hydrogen	H	1	1
Carbon	C	6	12
Nitrogen	N	7	14
Oxygen	O	8	16
Sodium	Na	11	23
Magnesium	Mg	12	24
Phosphorus	P	15	31
Sulfur	S	16	32
Chlorine	Cl	17	35
Potassium	K	19	39
Calcium	Ca	20	40
Iron	Fe	26	56
Iodine	I	53	127

*Hydrogen, carbon, nitrogen, and oxygen are the most abundant chemical elements in living organisms.

Electronic Configurations

- Electrons are arranged in electron shells corresponding to different energy levels

How Atoms Form Molecules

- Atoms combine to complete the outermost shell
- The number of missing or extra electrons in this shell is known as the **valence**
- Molecules hold together because the valence electrons of the combining atoms form attractive forces, called **chemical bonds**, between the atomic nuclei

Chemical Bonds

- A compound contains different kinds of atoms

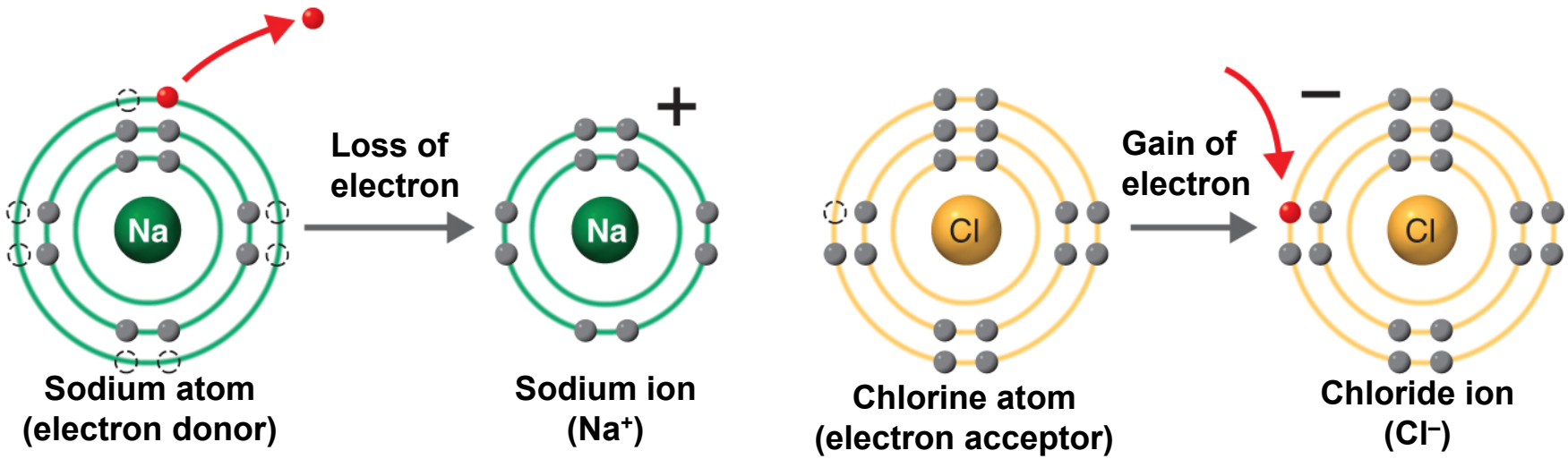
$$H_2O$$

Ionic Bonds

- The number of protons and electrons is equal in an atom

- Ions are charged atoms that have gained or lost electrons

Ionic bond formation.

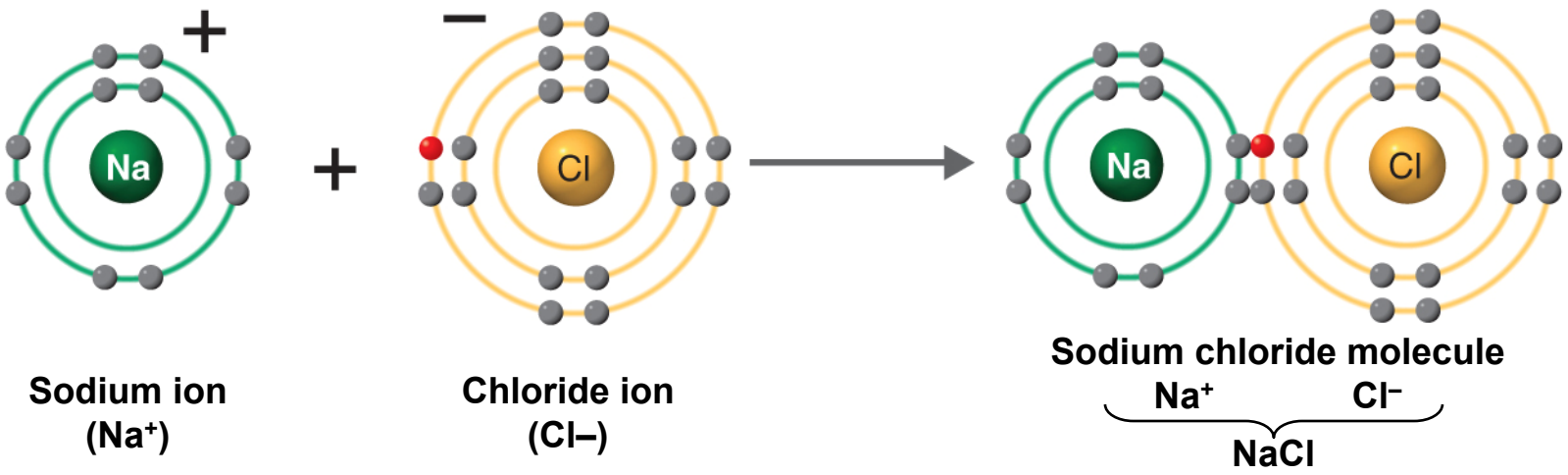


(a) A sodium atom (Na) loses one electron to an electron acceptor and forms a sodium ion (Na^+). A chlorine atom (Cl) accepts one electron from an electron donor to become a chloride ion (Cl^-).

Ionic Bonds

- **Ionic bonds** are attractions between ions of opposite charge
  - One atom loses electrons, and another gains electrons
  - The octet rule

Figure 2.2b Ionic bond formation.

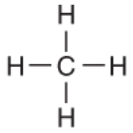
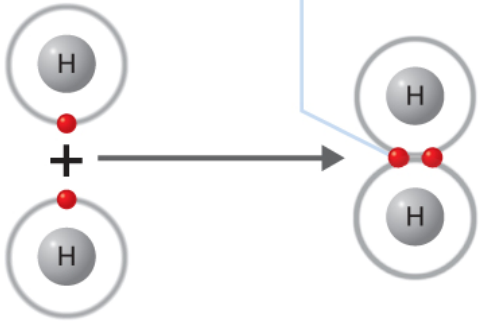
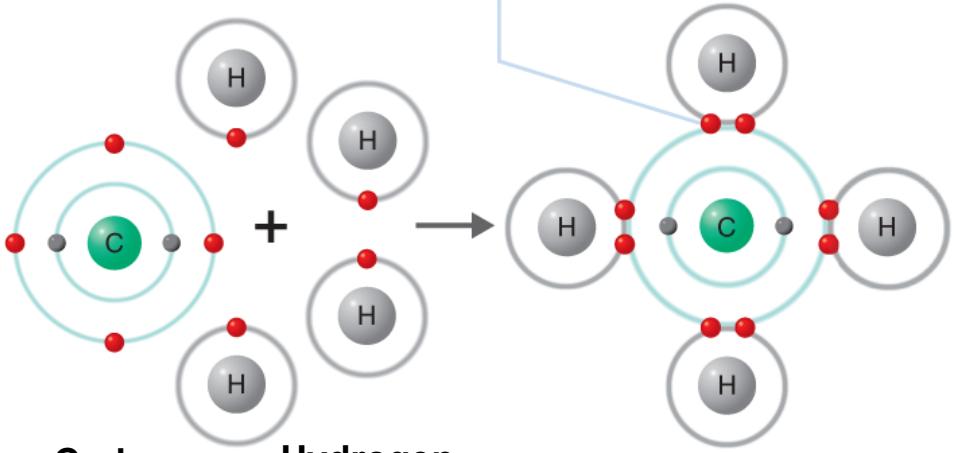


(b) The sodium and chloride ions are attracted because of their opposite charges and are held together by an ionic bond to form a molecule of sodium chloride.

Covalent Bonds

- **Covalent bonds** form when two atoms share one or more pairs of electrons

Covalent bond formation.

	Hydrogen	Methane
Molecular Formula	H_2	CH_4
Structural Formula	H—H	
Atomic Diagram		

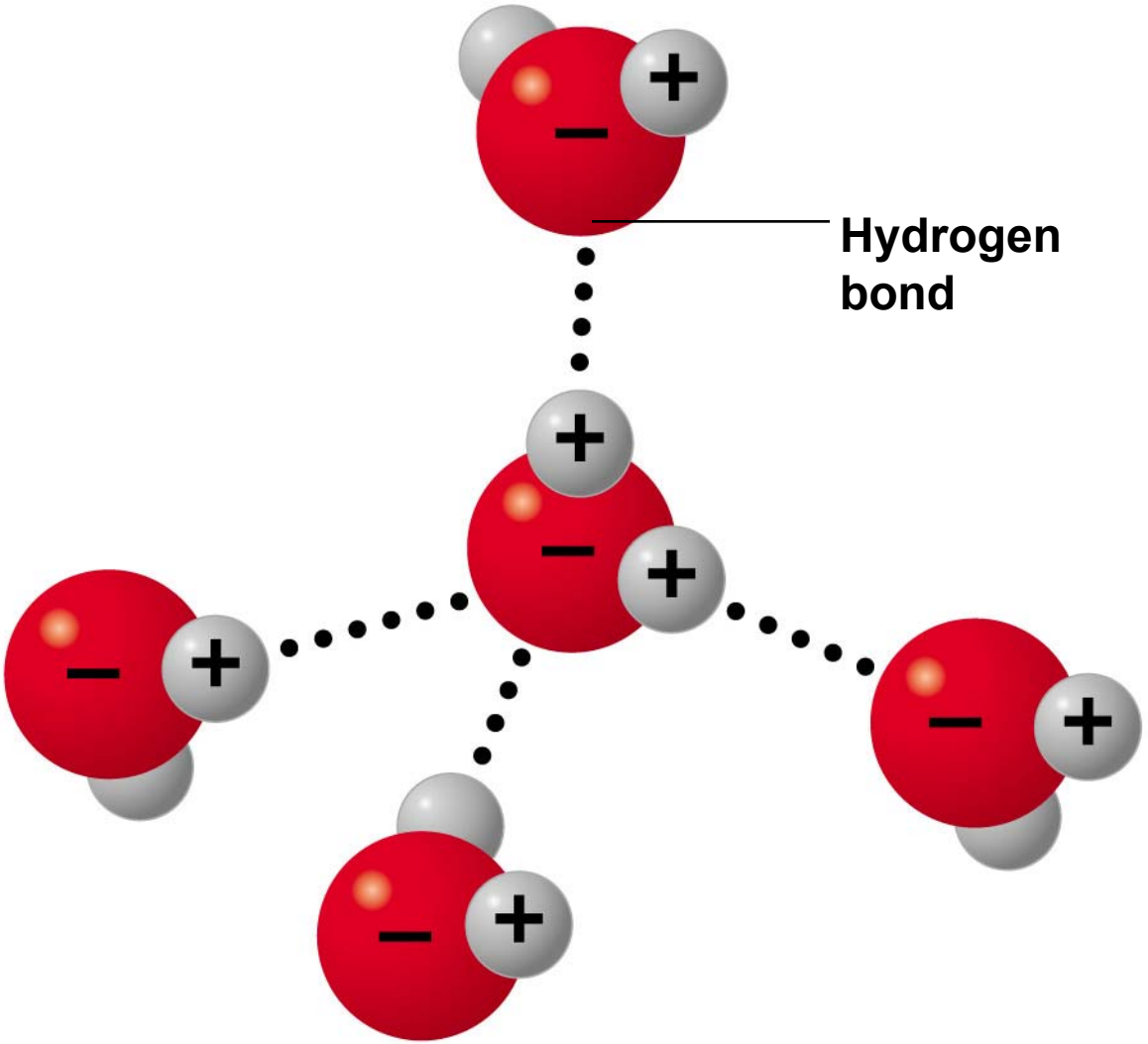
A single covalent bond forms between two hydrogen atoms to form a hydrogen molecule.

Single covalent bonds between four hydrogen atoms and a carbon atom, forming a methane molecule.

Hydrogen Bonds

- **Hydrogen bonds** form when a hydrogen atom that is covalently bonded to an O or N atom is attracted to another N or O atom in another molecule

Hydrogen bond formation in water.



Molecular Weight and Moles

- The sum of the atomic weights in a molecule is the **molecular weight**

- One **mole** of a substance is its molecular weight in grams

H_2O

2H	= 2 × 1	= 2
O		= 16
MW		= 18

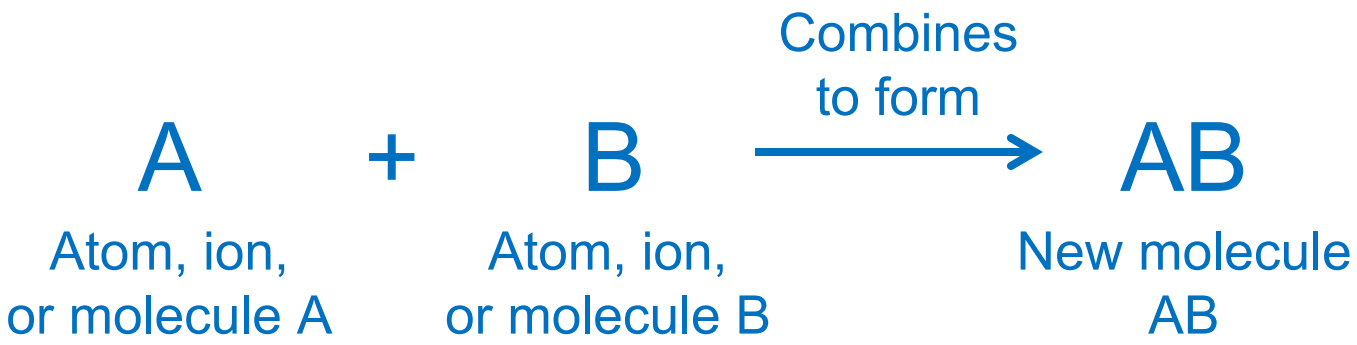
1 mole weighs 18 g

Chemical Reactions

- **Chemical reactions** involve the making or breaking of bonds between atoms
- A change in **chemical energy** occurs during a chemical reaction
- **Endergonic** reactions absorb energy
- **Exergonic** reactions release energy

Synthesis Reactions

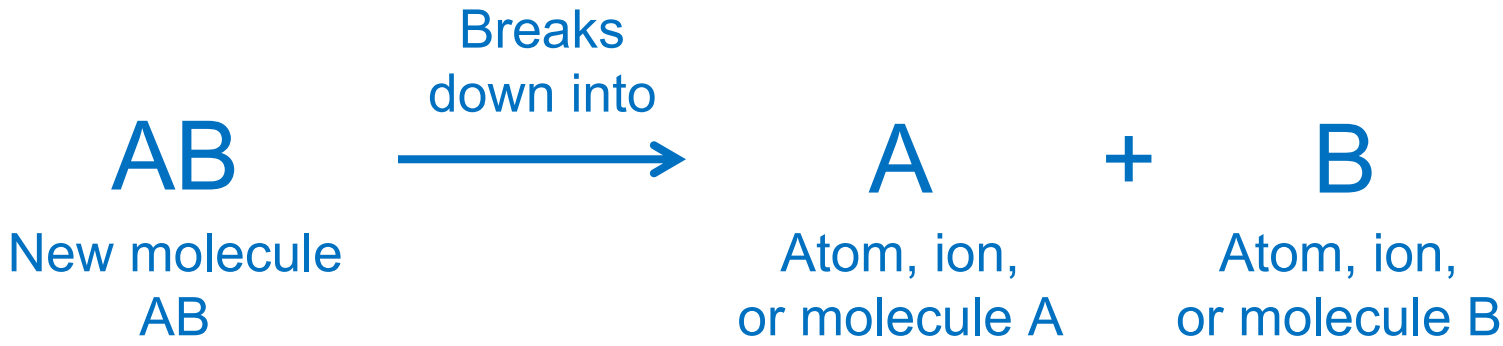
- Occur when atoms, ions, or molecules combine to form new, larger molecules



- **Anabolism** is the synthesis of molecules in a cell

Decomposition Reactions

- Occur when a molecule is split into smaller molecules, ions, or atoms



- **Catabolism** is the decomposition reactions in a cell

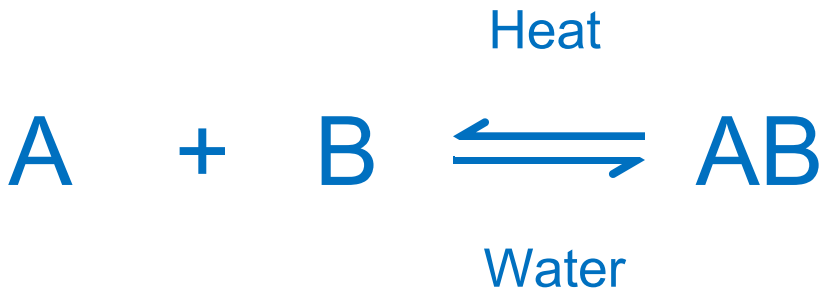
Exchange Reactions

- Are part synthesis and part decomposition

$$NaOH + HCl \longrightarrow NaCl + H_2O$$

Reversible Reactions

- Can readily go in either direction
- Each direction may need special conditions



Important Biological Molecules

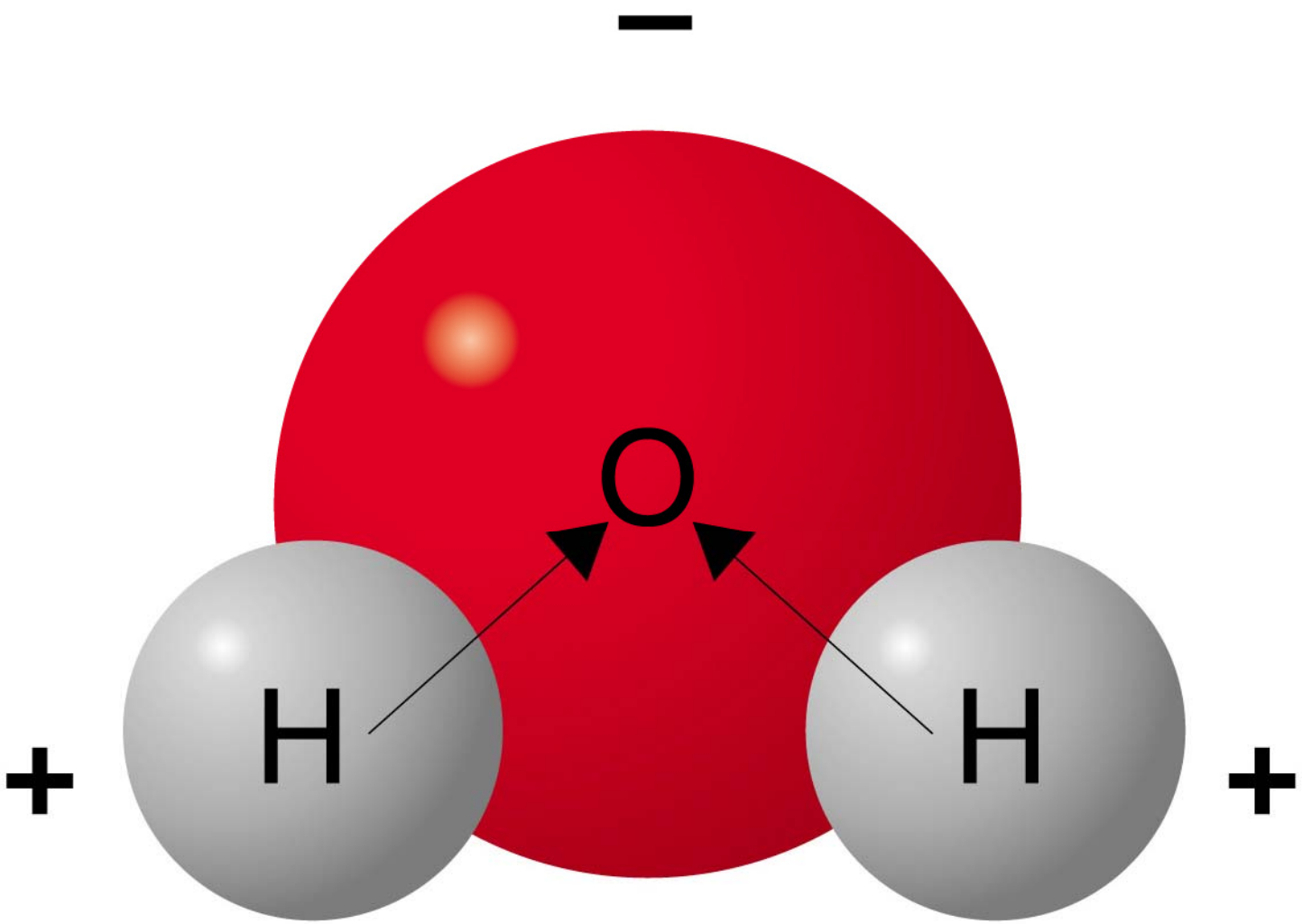
- **Organic compounds** always contain carbon and hydrogen

- **Inorganic compounds** typically lack carbon

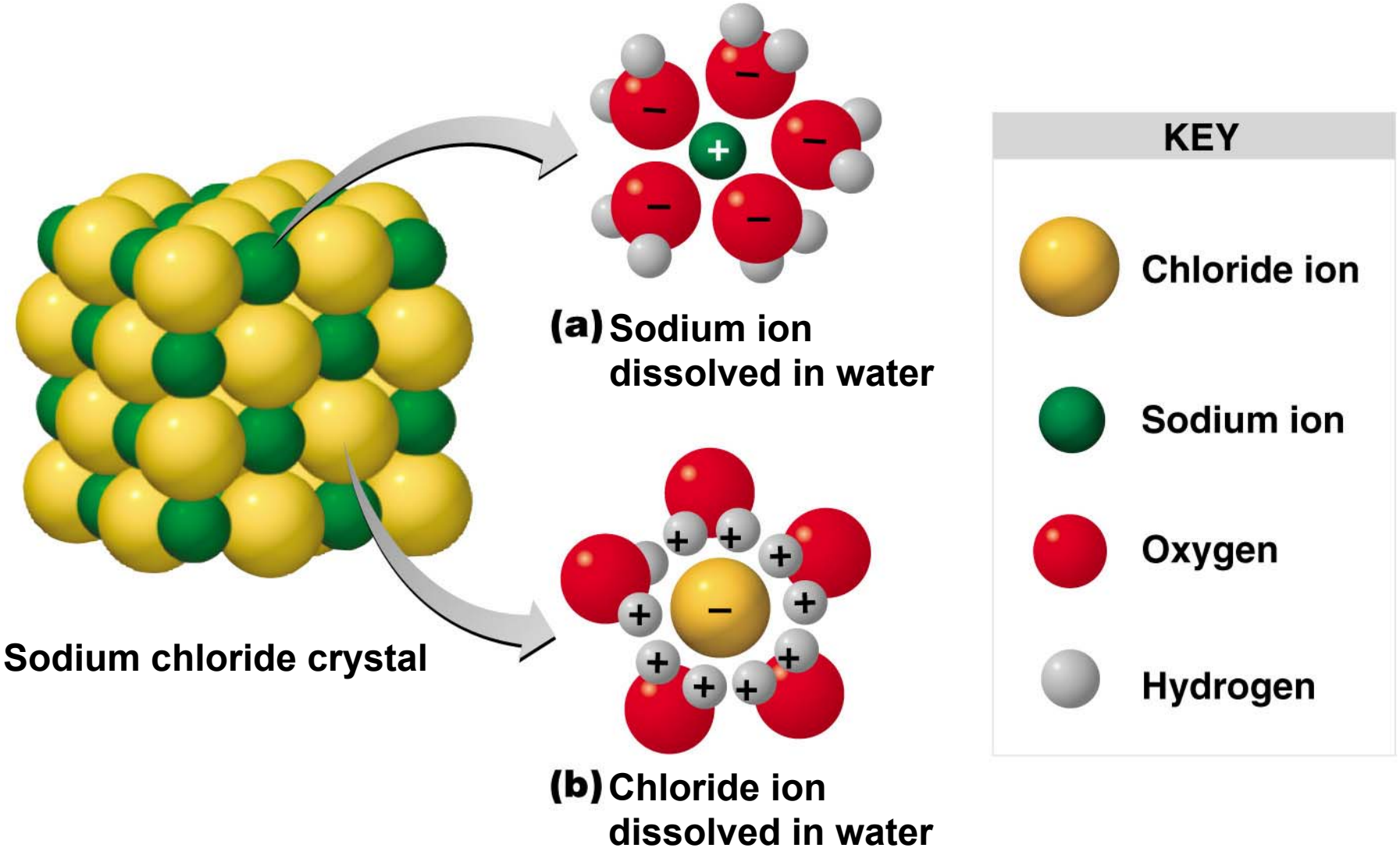
Water

- Inorganic
- Polar covalent molecule
- Solvent // Polar substances dissociate, forming solutes

Hydrogen bond formation in water.

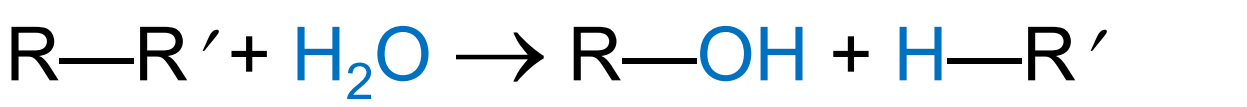


How water acts as a solvent for sodium chloride (NaCl).



Water

- H^+ and OH^- participate in chemical reactions



Water

Maltose + $H_2O \rightarrow$ Glucose + Glucose

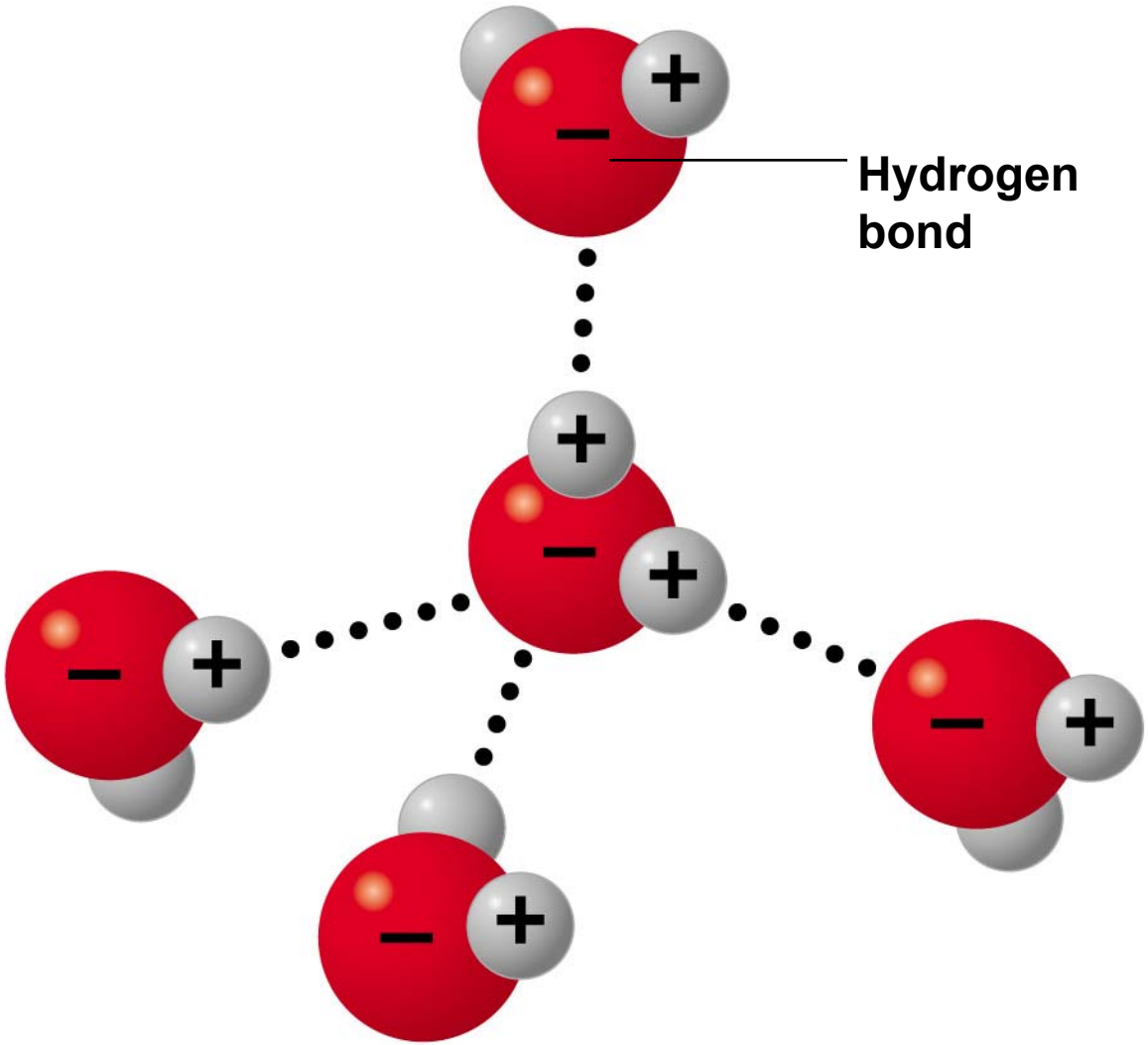
Glucose	$C_6H_{12}O_6$
Glucose	$+C_6H_{12}O_6$
Total	$C_{12}H_{24}O_{12}$
Maltose	$C_{12}H_{22}O_{11}$

The difference is: _____

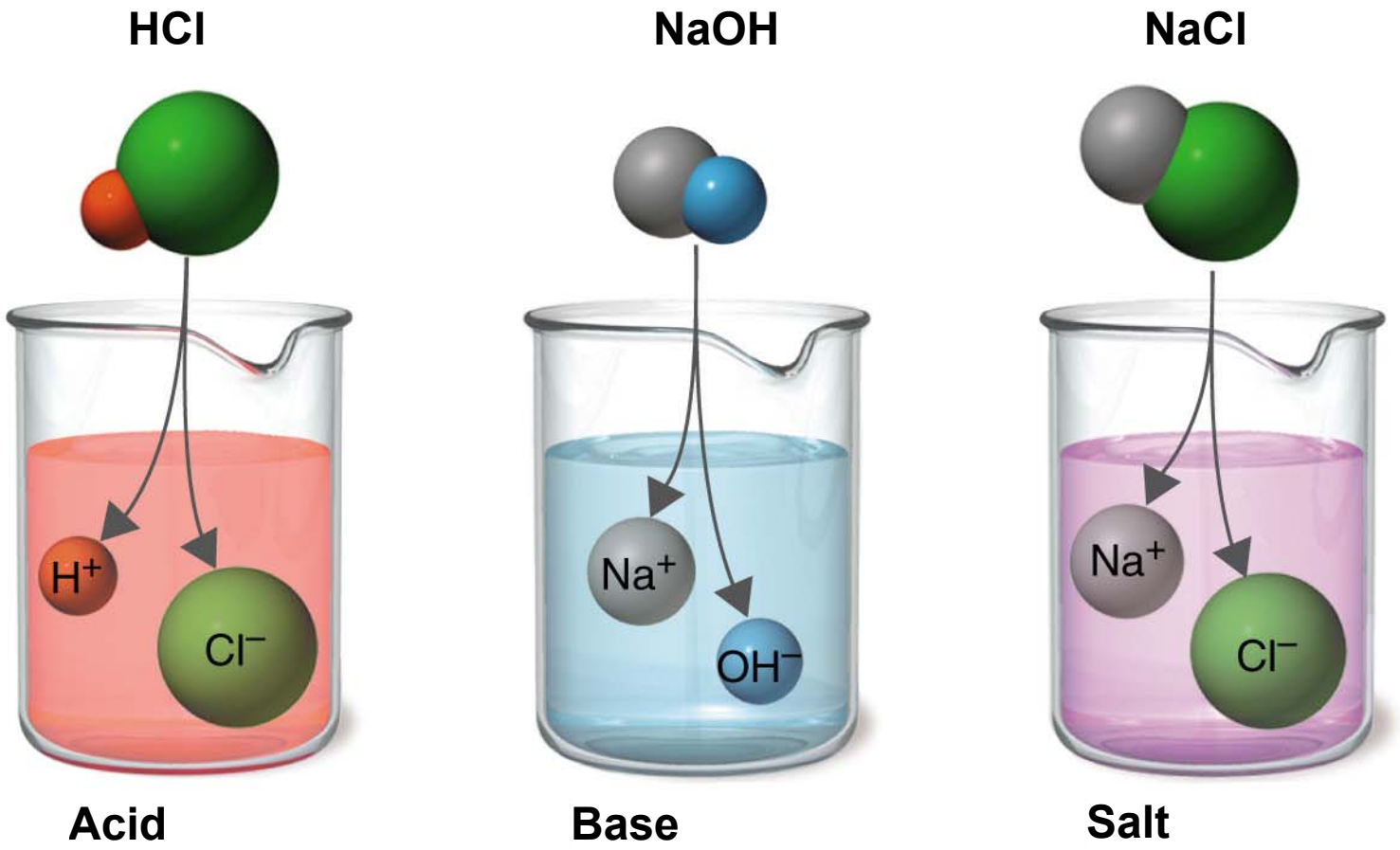
Water

- H bonds absorb heat
  - Makes water a temperature buffer

Hydrogen bond formation in water.



Acids, bases, and salts.

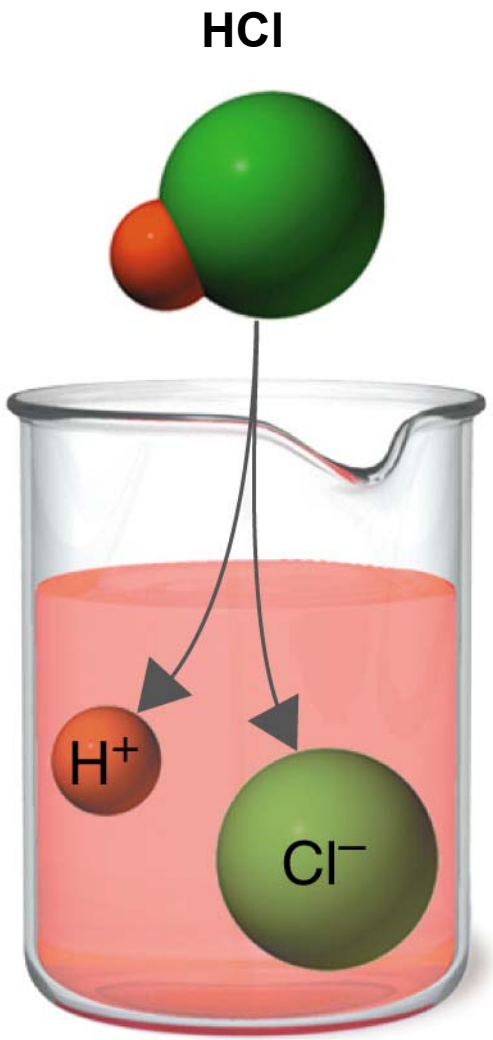


Acids

- Substances that dissociate into one or more H^+

$$HCl \rightarrow H^+ + Cl^-$$

Acids, bases, and salts.



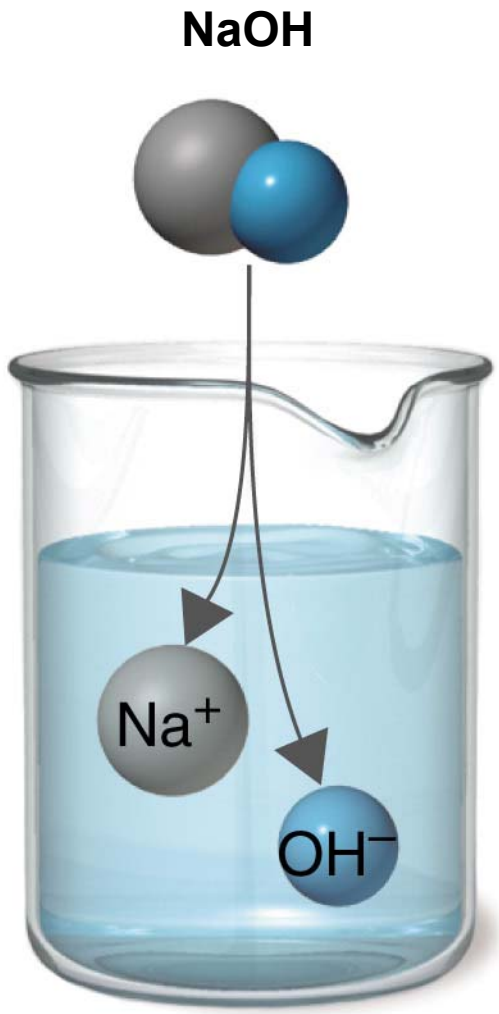
(a) Acid

Bases

- Substances that dissociate into one or more OH^-

$$NaOH \rightarrow Na^+ + OH^-$$

Acids, bases, and salts.



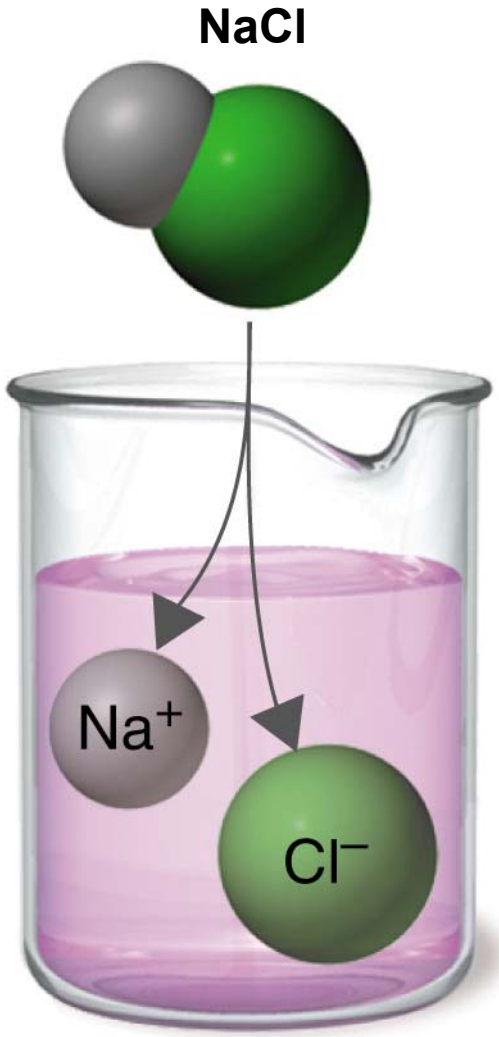
(b) Base

Salts

- Substances that dissociate into cations and anions, neither of which is H^+ or OH^-

$$NaCl \rightarrow Na^+ + Cl^-$$

Acids, bases, and salts.

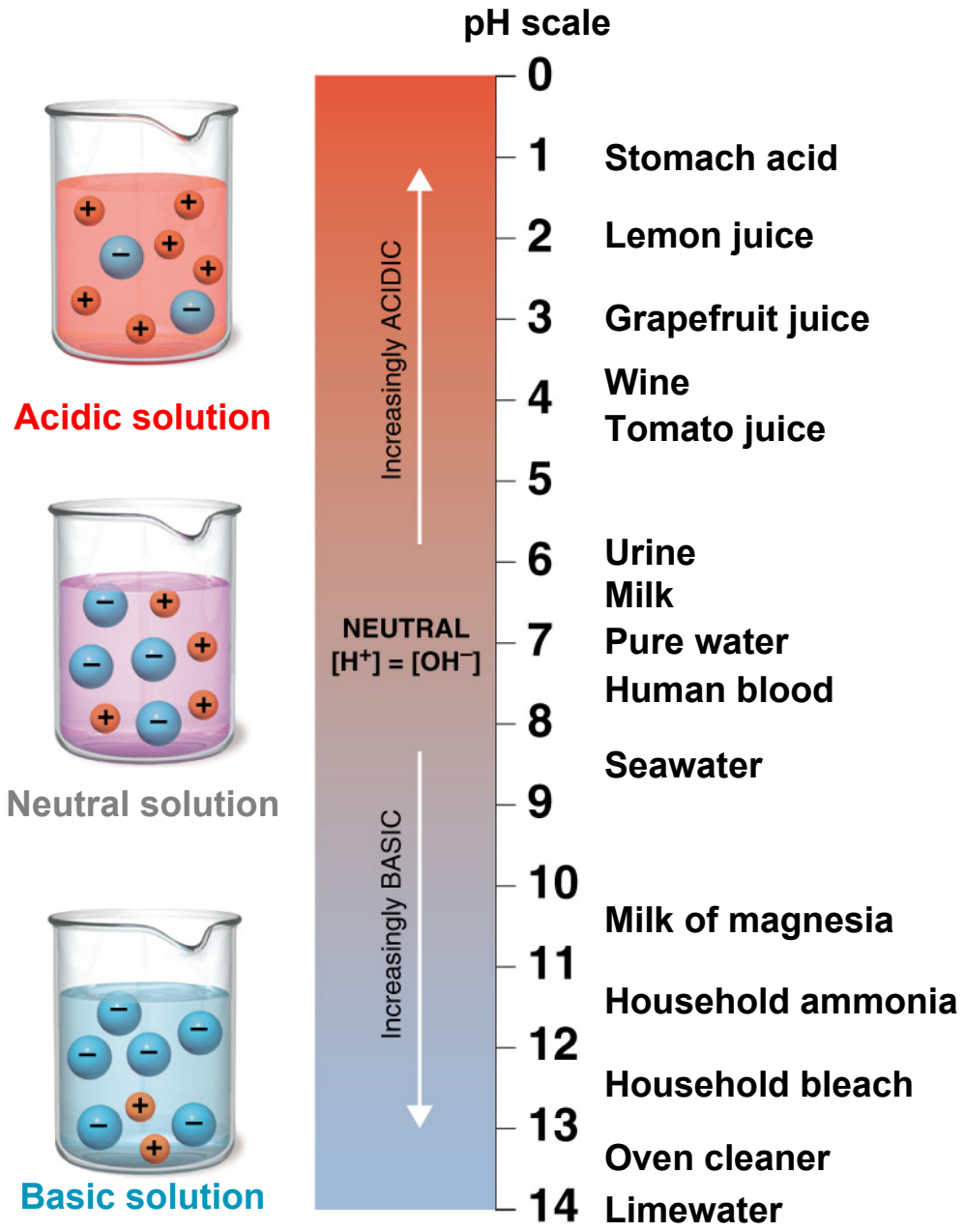


(c) Salt

Acid-Base Balance

- The amount of H^+ in a solution is expressed as **pH**
- $pH = -\log[H^+]$
- Increasing $[H^+]$ increases acidity
- Increasing $[OH^-]$ increases alkalinity
- Most organisms grow best between pH 6.5 and 8.5

The pH scale.

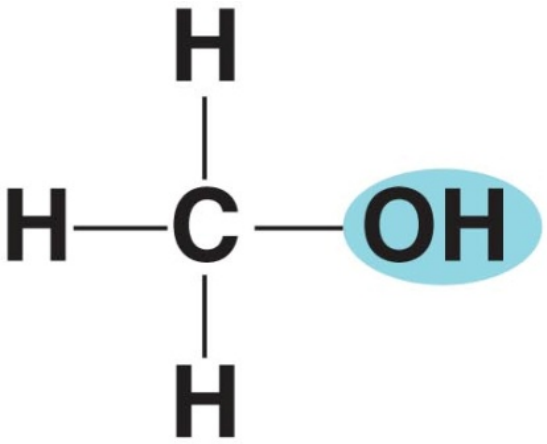

pH scale
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Stomach acid
Lemon juice
Grapefruit juice
Wine
Tomato juice
Urine
Milk
Pure water
Human blood
Seawater
Milk of magnesia
Household ammonia
Household bleach
Oven cleaner
Limewater
Increasingly ACIDIC
NEUTRAL
[H+] = [OH−]
Increasingly BASIC
Acidic solution
Neutral solution
Basic solution

Structure and Chemistry

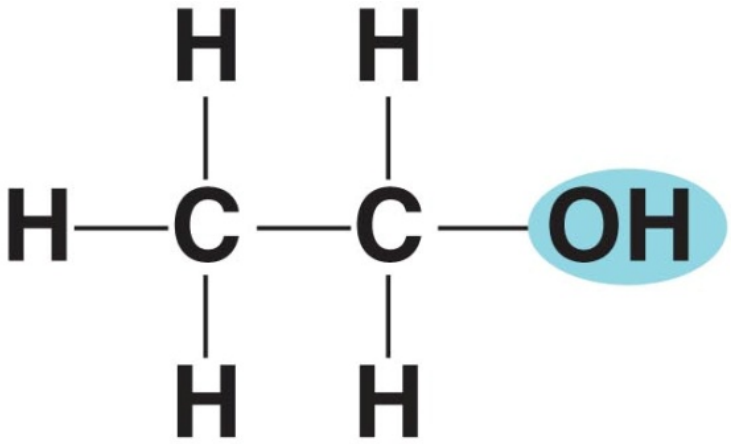
- The chain of carbon atoms in an organic molecule is the **carbon skeleton**

Structure and Chemistry

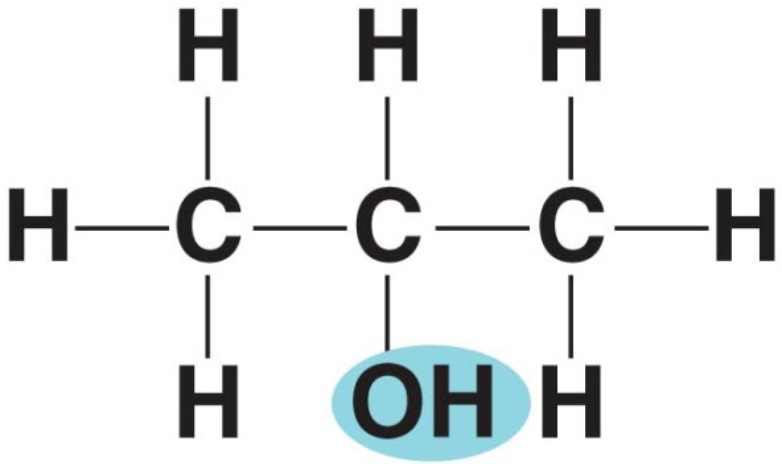
- **Functional groups** are responsible for most of the chemical properties of a particular organic compound



Methanol

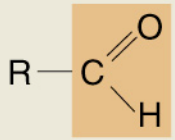
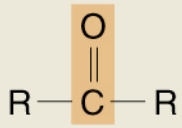
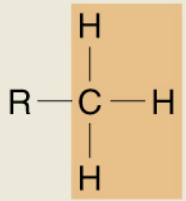
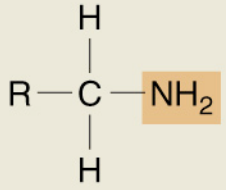


Ethanol



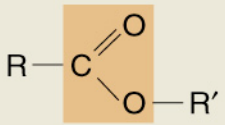
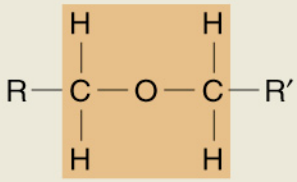
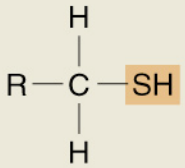
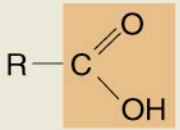
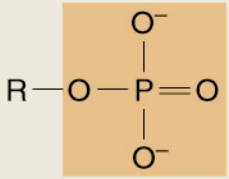
Isopropanol

TABLE 2.4 Representative Functional Groups and the Compounds in Which They Are Found

Structure	Name of Group	Biological Importance
	Alcohol	Lipids, carbohydates
	Aldehyde*	Reducing sugars such as glucose; polysaccharides
	Ketone*	Metabolic intermediates
	Methyl	DNA; energy metabolism
	Amino	Proteins

*In an aldehyde, a C═O is at the end of a molecule, in contrast to the internal C═O in a ketone.

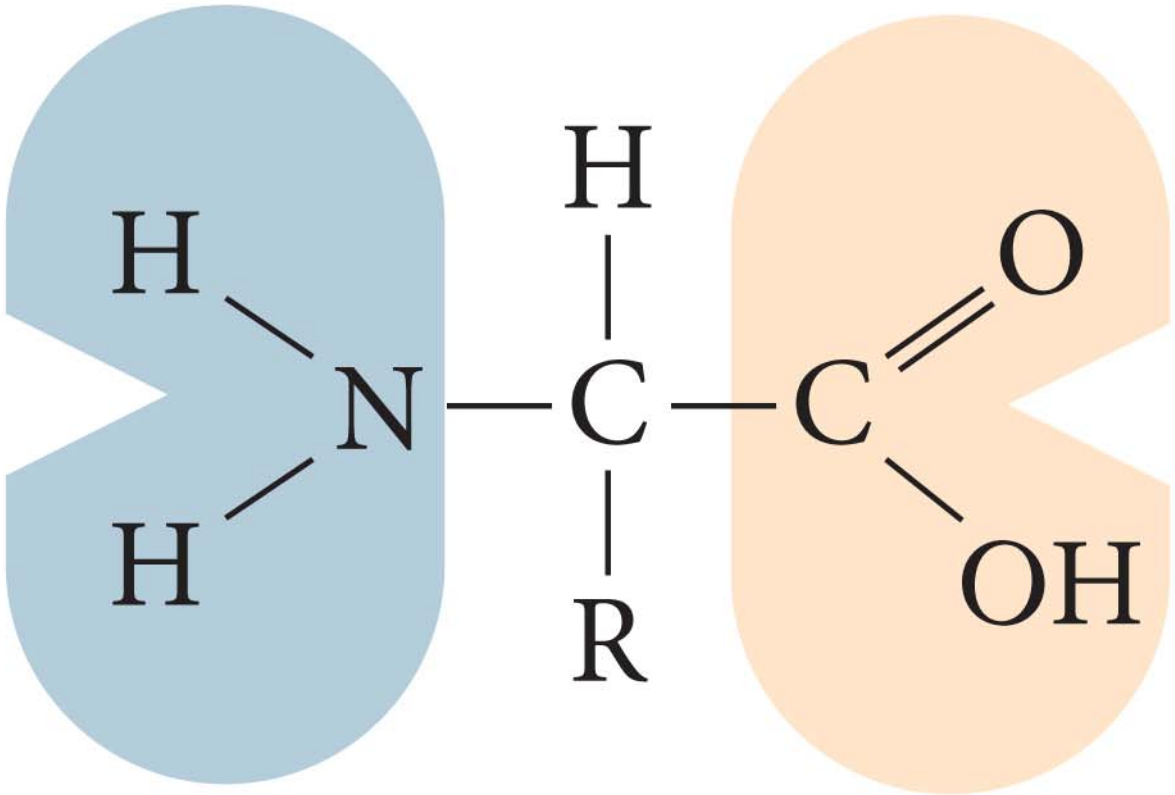
TABLE 2.4 Representative Functional Groups and the Compounds in Which They Are Found

Structure	Name of Group	Biological Importance
	Ester	Bacterial and eukaryotic plasma membranes
	Ether	Archaeal plasma membranes
	Sulfhydryl	Energy metabolism; protein structure
	Carboxyl	Organic acids, lipids, proteins
	Phosphate	ATP, DNA

*In an aldehyde, a C═O is at the end of a molecule, in contrast to the internal C═O in a ketone.

Functional Groups

- Identify the functional groups in an amino acid



Organic Compounds

- Small organic molecules can combine into large macromolecules
- **Macromolecules** are polymers consisting of many small repeating molecules
- The smaller molecules are called **monomers**

Polymers

- Monomers join by **dehydration synthesis** or **condensation reactions**

Carbohydrates

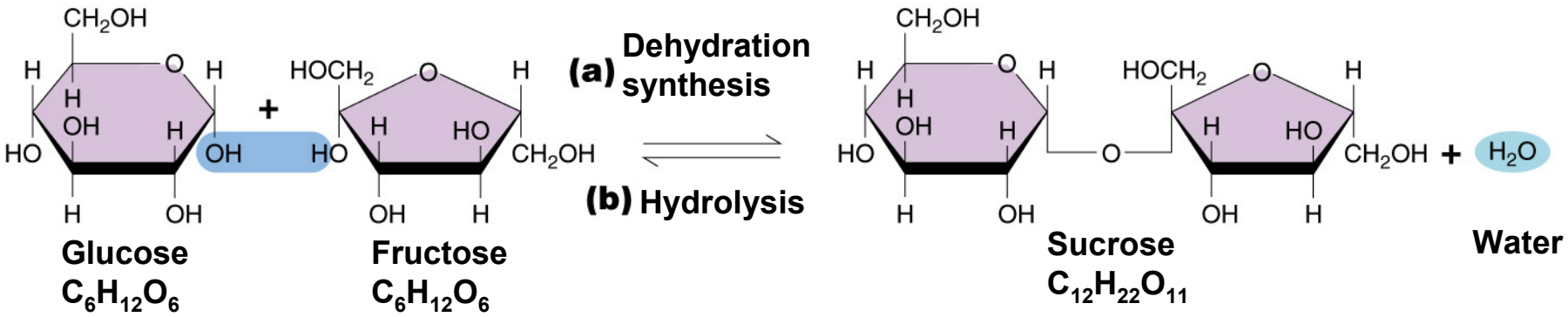
- Cell structures and energy sources
- Consist of C, H, and O with the formula $(CH_2O)_n$
- **Monosaccharides** are simple sugars with three to seven carbon atoms

Carbohydrates

- **Disaccharides** are formed when two monosaccharides are joined in a dehydration synthesis

- Disaccharides can be broken down by hydrolysis

Dehydration synthesis and hydrolysis.



Carbohydrates

- **Oligosaccharides** consist of 2 to 20 monosaccharides
- **Polysaccharides** consist of tens or hundreds of monosaccharides joined through dehydration synthesis
  - Starch, glycogen, dextran, and cellulose are polymers of glucose that are covalently bonded differently
  - Chitin is a polymer of two sugars repeating many times

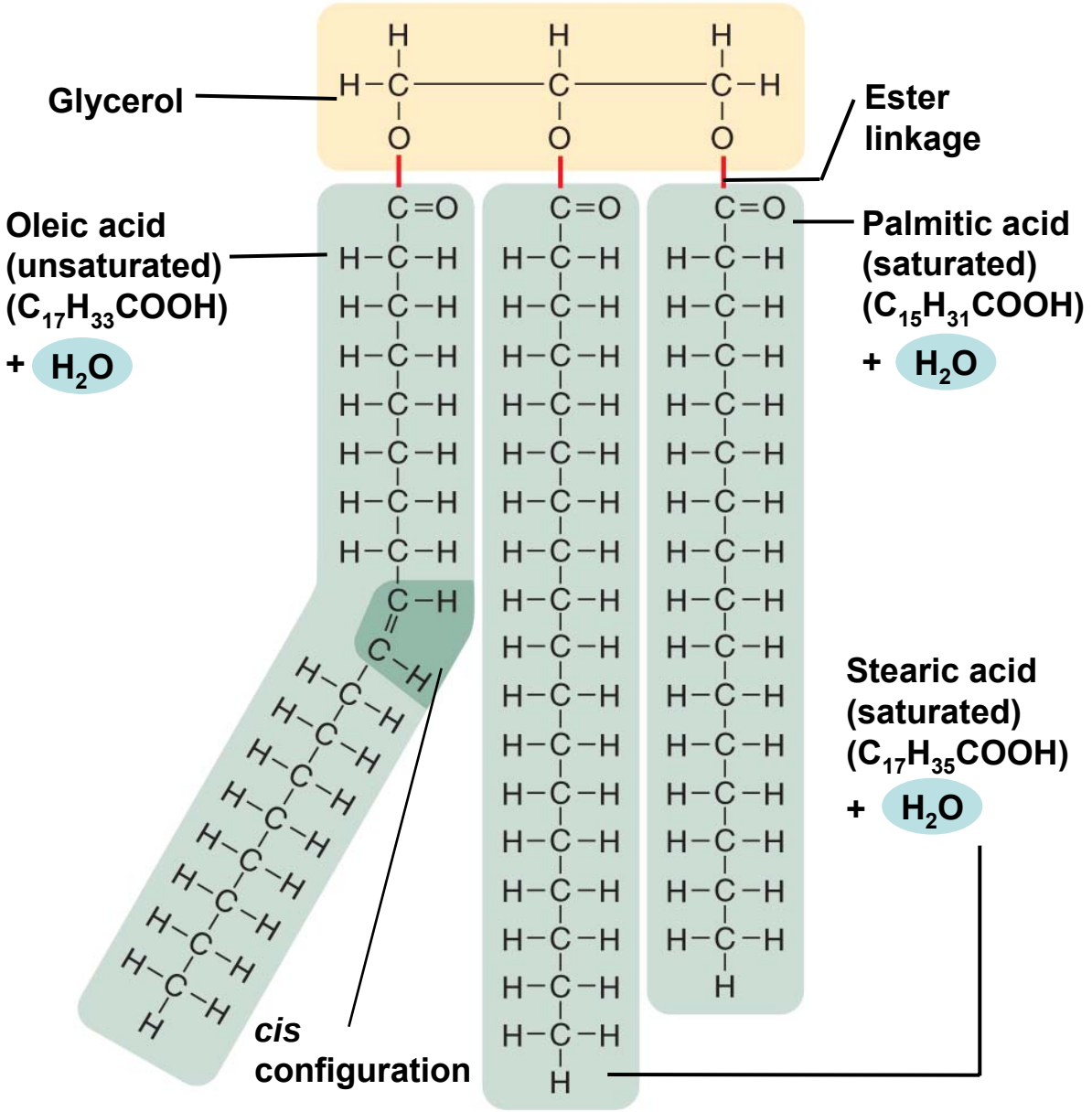
Lipids

- Primary components of cell membranes
- Consist of C, H, and O
- Are nonpolar and insoluble in water

Simple Lipids

- **Fats** or **triglycerides**
- Contain glycerol and fatty acids; formed by dehydration synthesis

Structural formulas of simple lipids.

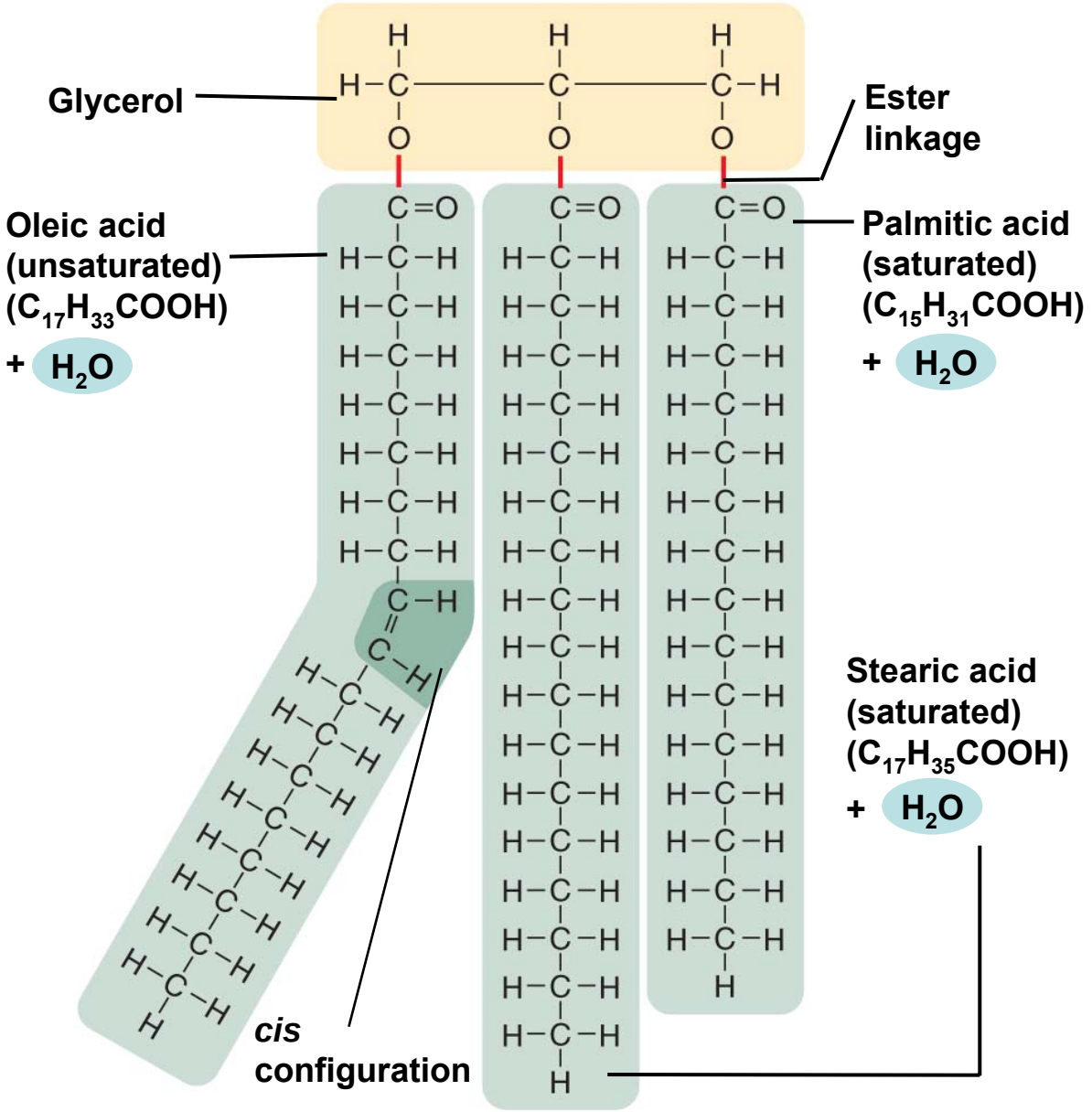


(c) Molecule of fat (triglyceride)

Simple Lipids

- **Saturated fat**: no double bonds
- **Unsaturated fat**: one or more double bonds in the fatty acids
  - ***Cis***: H atoms on the same side of the double bond
  - ***Trans***: H atoms on opposite sides of the double bond

Structural formulas of simple lipids.

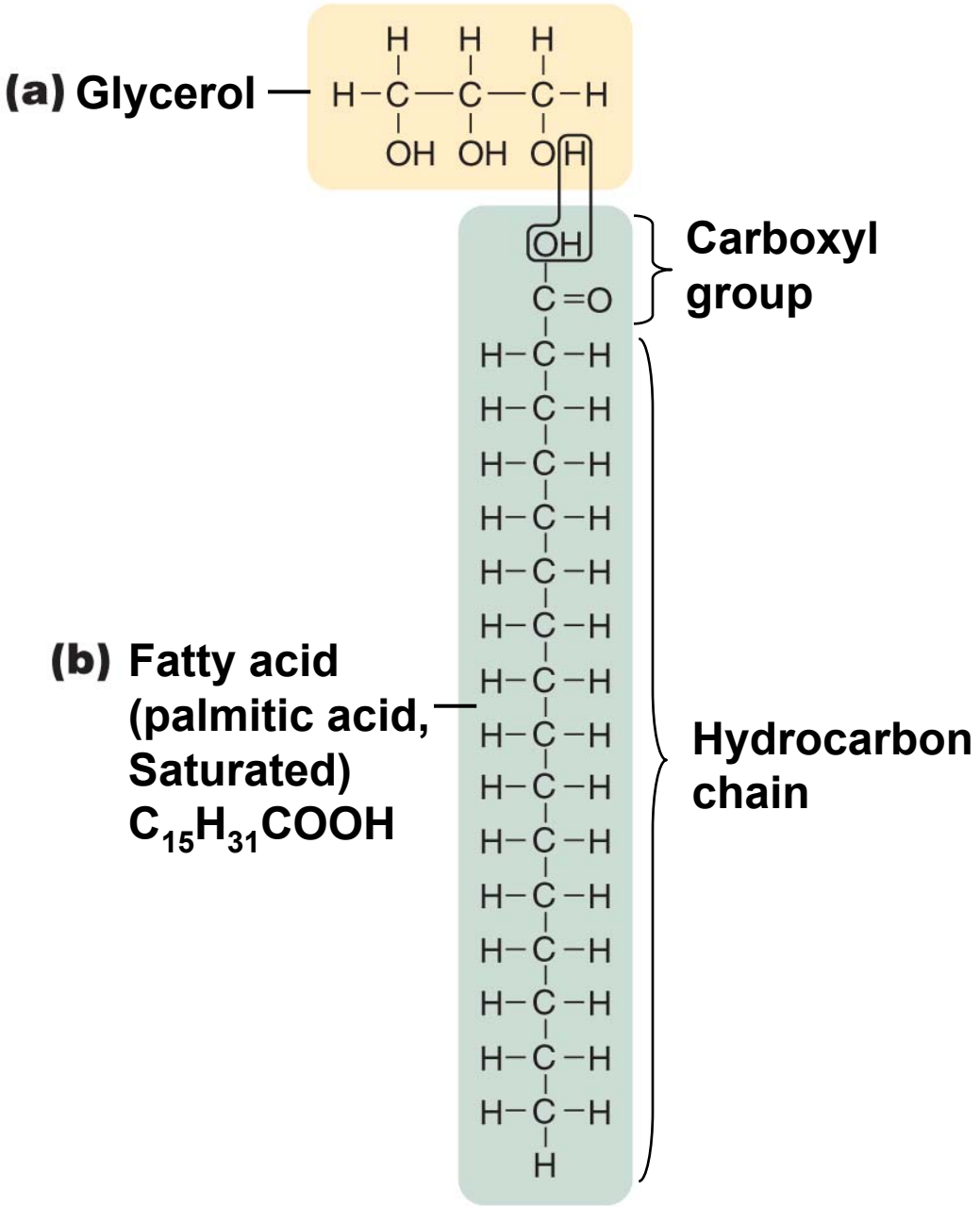


(c) Molecule of fat (triglyceride)

Complex Lipids

- Contain C, H, and O + P, N, or S
- Membranes are made of phospholipids

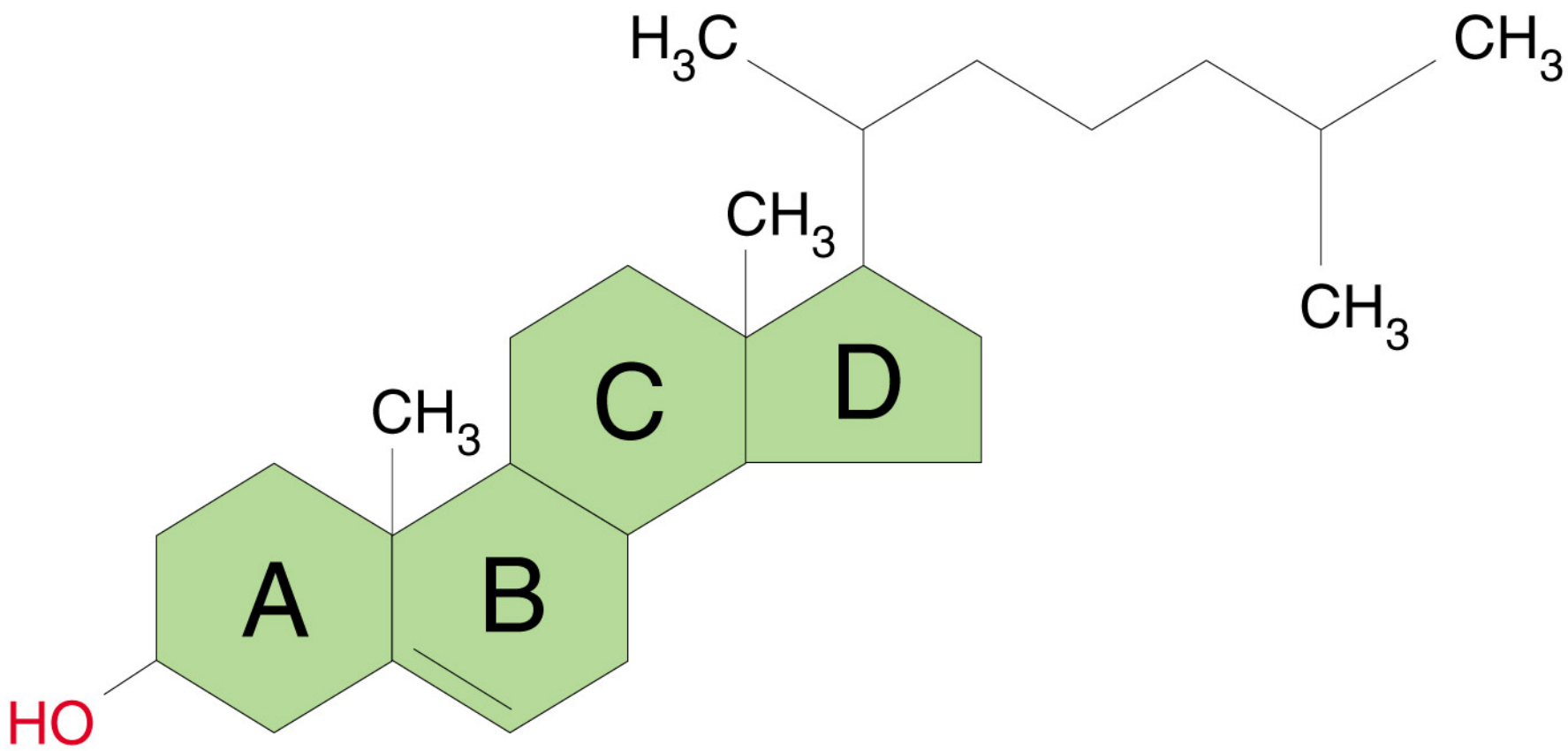
Structural formulas of simple lipids.



Steroids

- Four carbon rings with an –OH group attached to one ring
- Part of membranes

Cholesterol, a steroid.



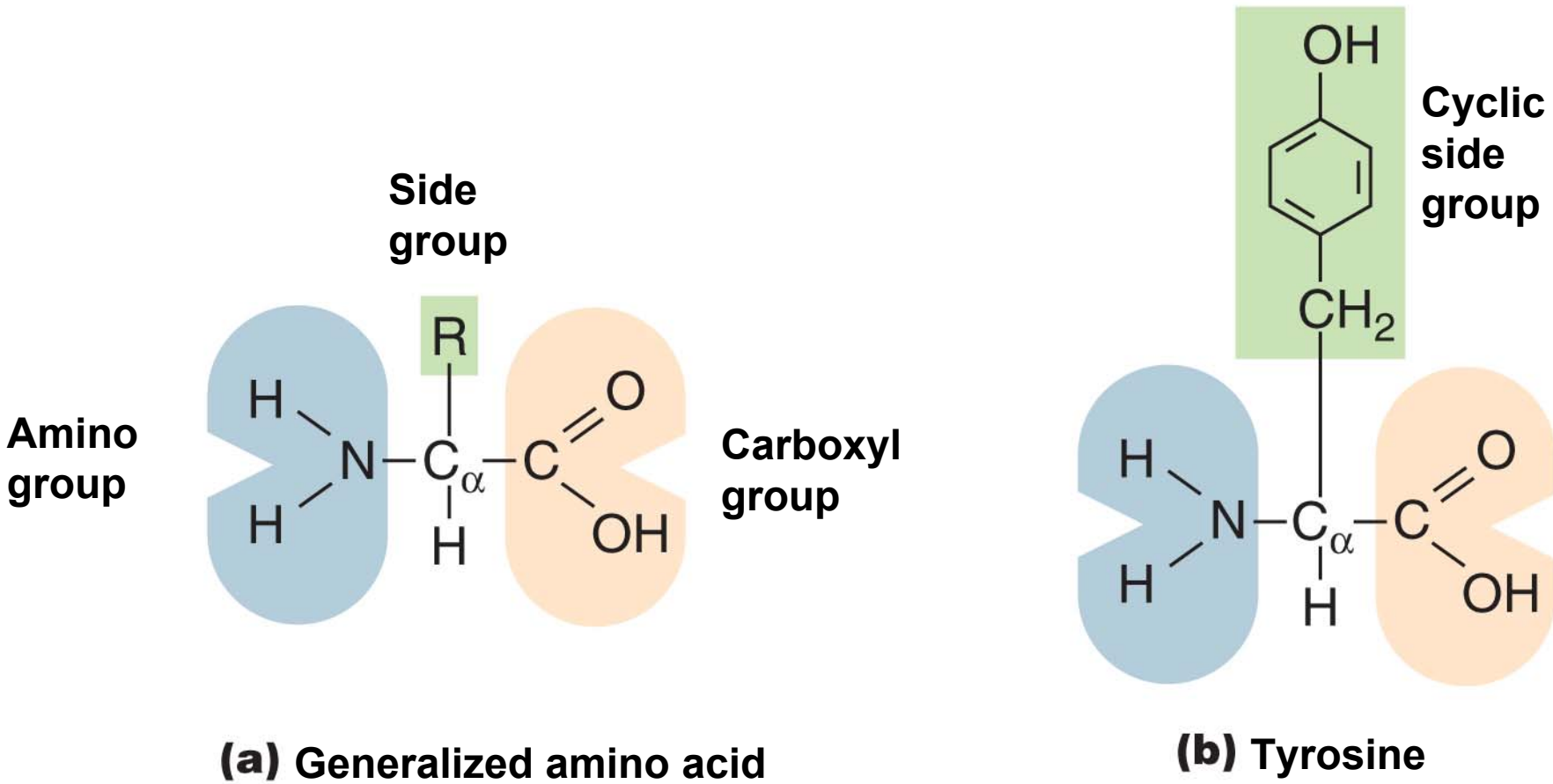
Proteins

- Are essential in cell structure and function
- Enzymes are proteins that speed chemical reactions
- Transporter proteins move chemicals across membranes
- Flagella are made of proteins
- Some bacterial toxins are proteins

Amino Acids

- Proteins consist of subunits called **amino acids**

Amino acid structure.

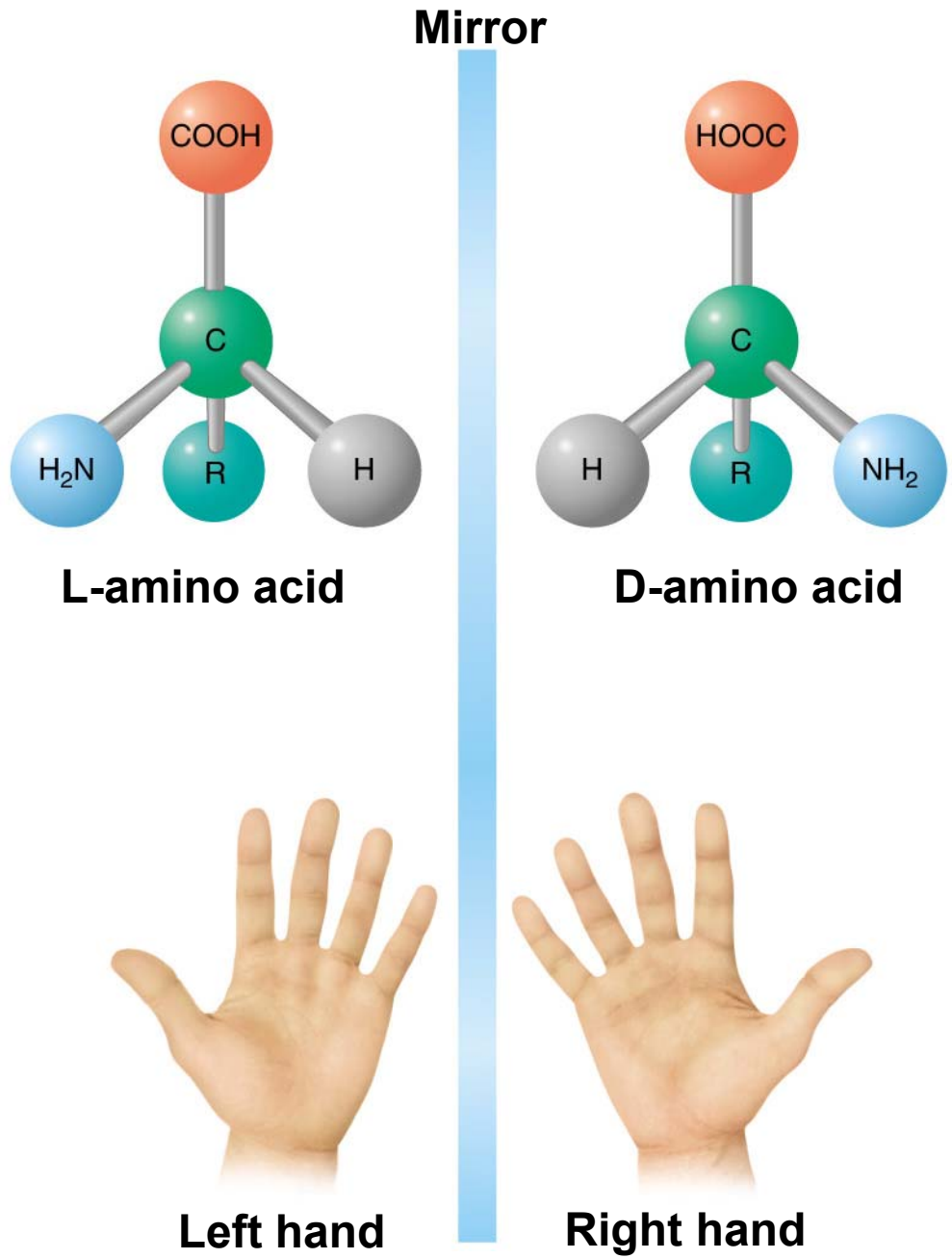


Amino Acids

- Exist in either of two **stereoisomers**: D or L

- L-forms are most often found in nature

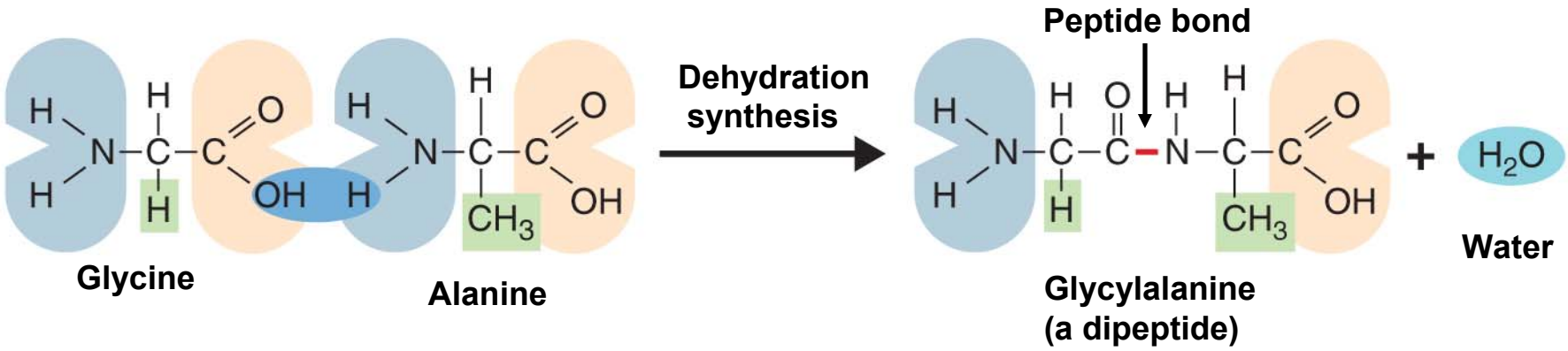
The L- and D-isomers of an amino acid, shown with ball-and-stick models.



Peptide Bonds

- **Peptide bonds** between amino acids are formed by dehydration synthesis

Peptide bond formation by dehydration synthesis.

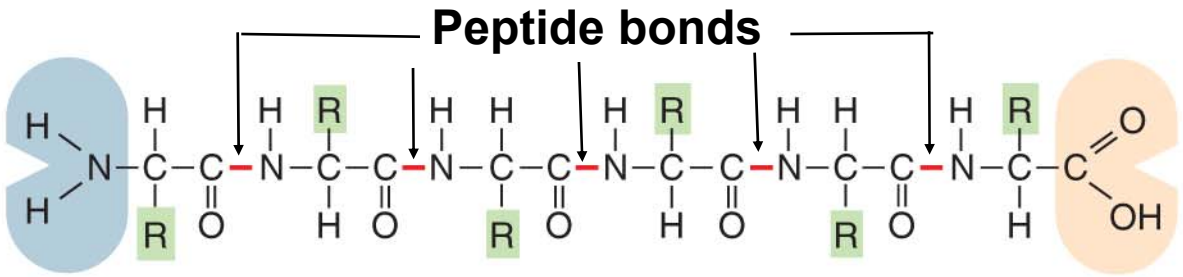


Levels of Protein Structure

- The **primary structure** is a polypeptide chain

Protein structure.

1 **Primary structure:** polypeptide strand (amino acid sequence)

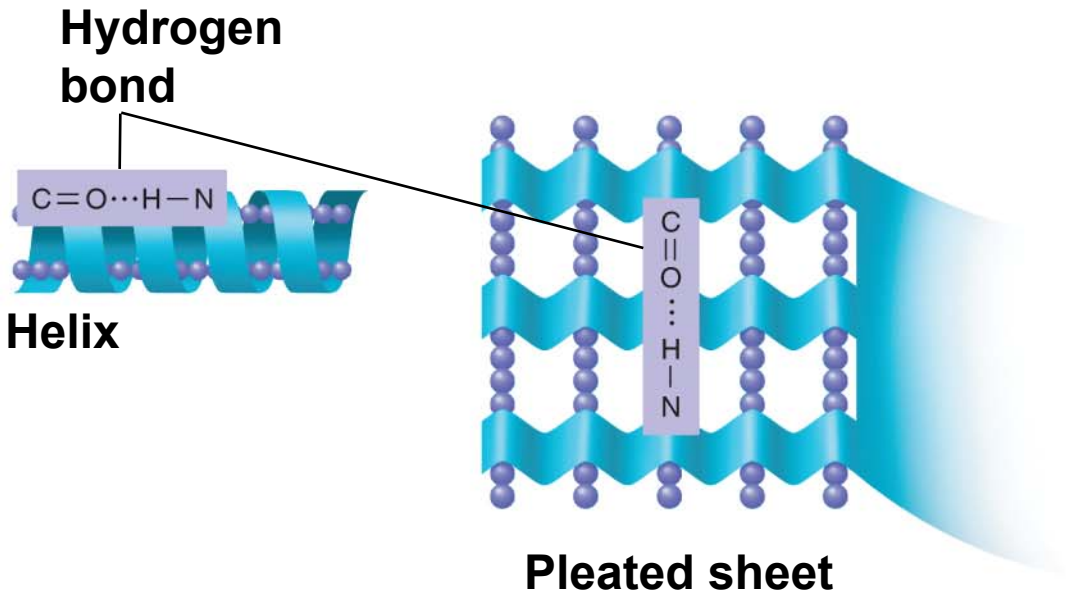


Levels of Protein Structure

- The **secondary structure** occurs when the amino acid chain folds and coils in a regular helix or pleats

Protein structure.

2 **Secondary structure:** helix and pleated sheet (with three polypeptide strands)

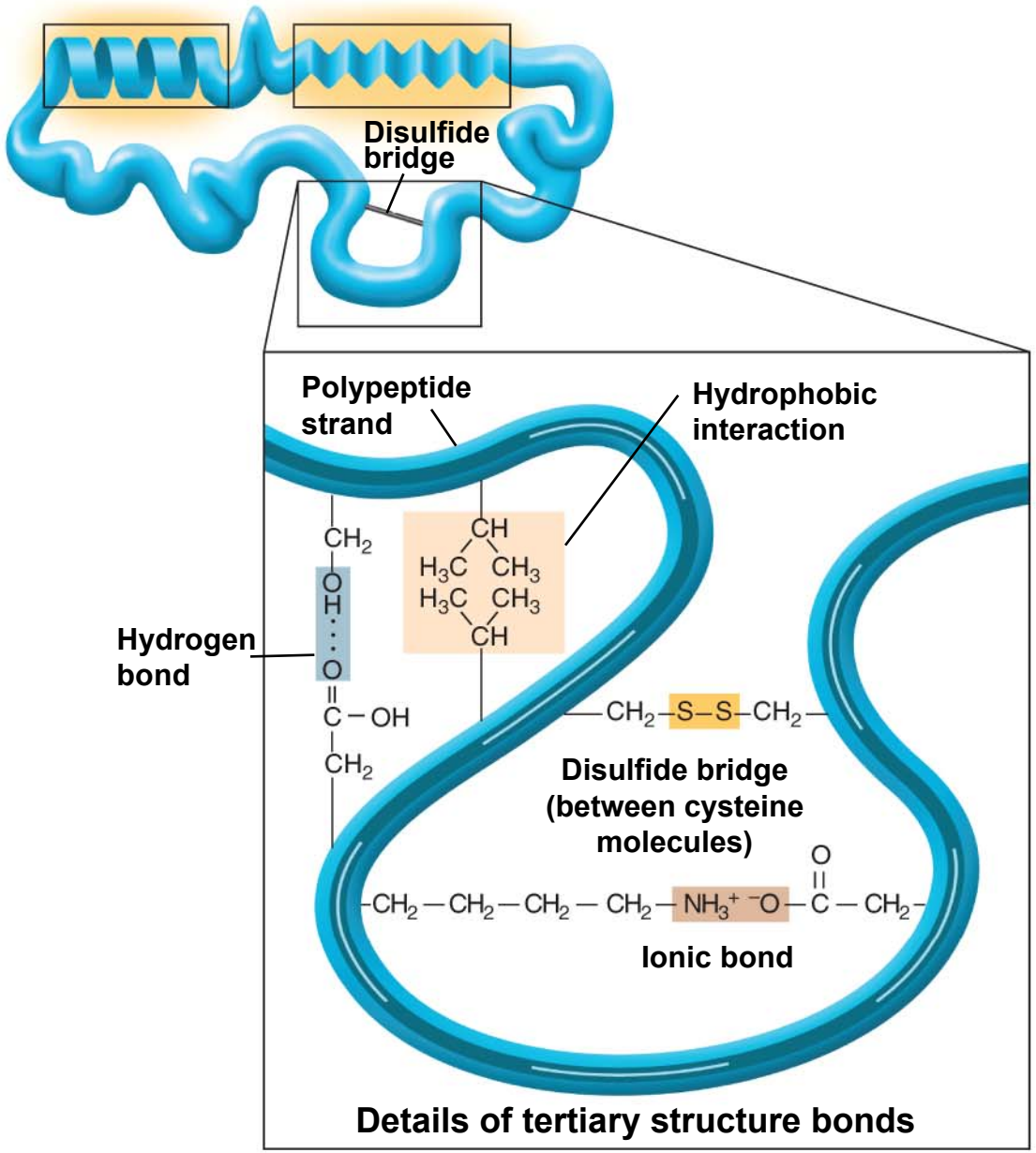


Levels of Protein Structure

- The **tertiary structure** occurs when the helix folds irregularly, forming disulfide bridges, hydrogen bonds, and ionic bonds between amino acids in the chain

Protein structure.

3 **Tertiary structure:** helix and pleated sheets fold into a 3D shape



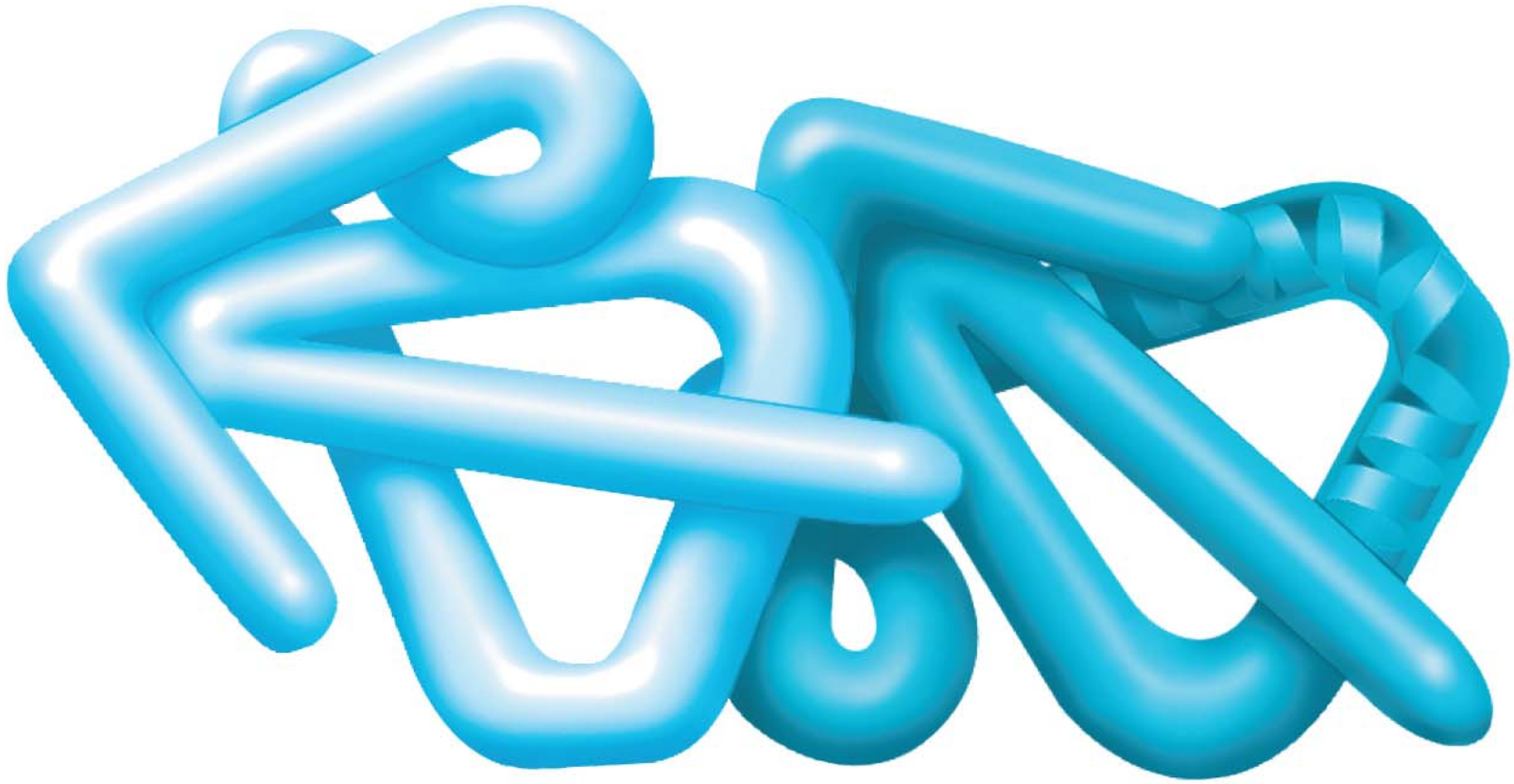
Levels of Protein Structure

- The **quaternary structure** consists of two or more polypeptides

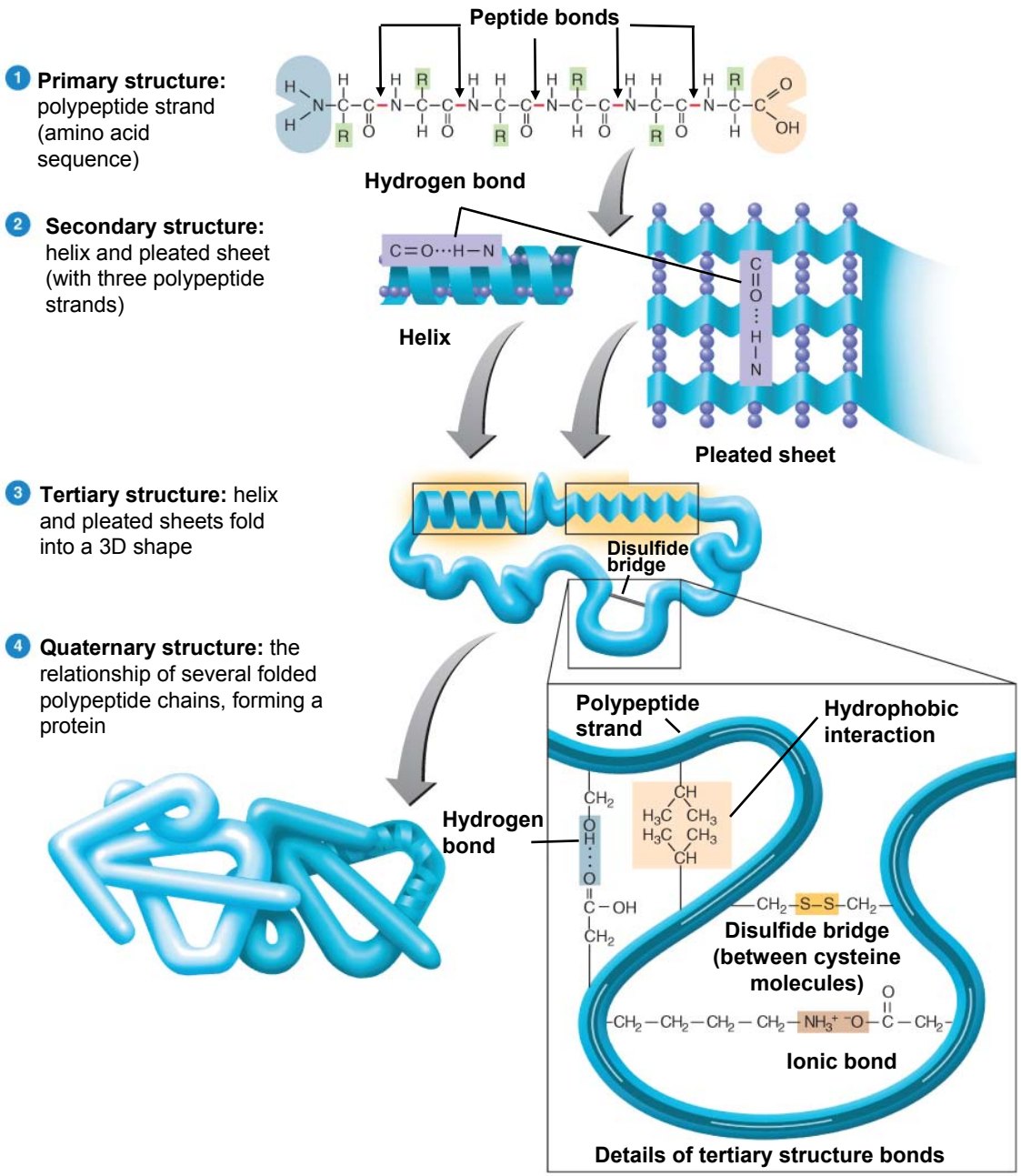
Protein structure.

4

Quaternary structure:
the relationship of several folded polypeptide chains, forming a protein



Protein structure.



Levels of Protein Structure

- Conjugated proteins consist of amino acids and other organic molecules
  - Glycoproteins
  - Nucleoproteins
  - Lipoproteins

Nucleic Acids

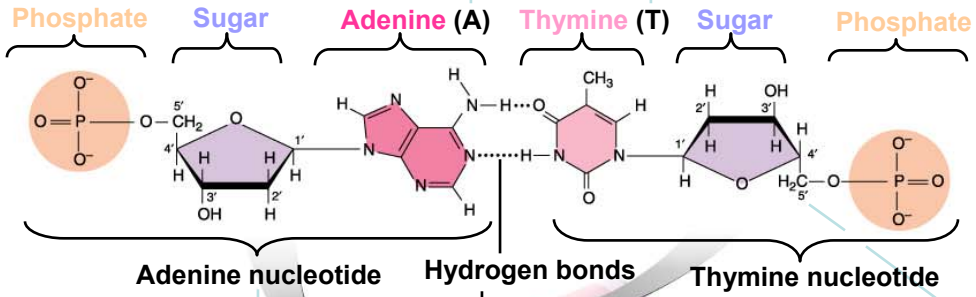
- Consist of **nucleotides**
- Nucleotides consist of
  - Pentose
  - Phosphate group
  - Nitrogen-containing (**purine** or **pyrimidine**) base
- **Nucleosides** consist of
  - Pentose
  - Nitrogen-containing base

DNA

- **Deoxyribonucleic acid**
- Has deoxyribose
- Exists as a double helix
- **A** hydrogen bonds with **T**
- **C** hydrogen bonds with **G**

The Structure of DNA.

Adenine and Thymine (as well as Cytosine and Guanine, not shown here) are nitrogenous bases or nucleobases.



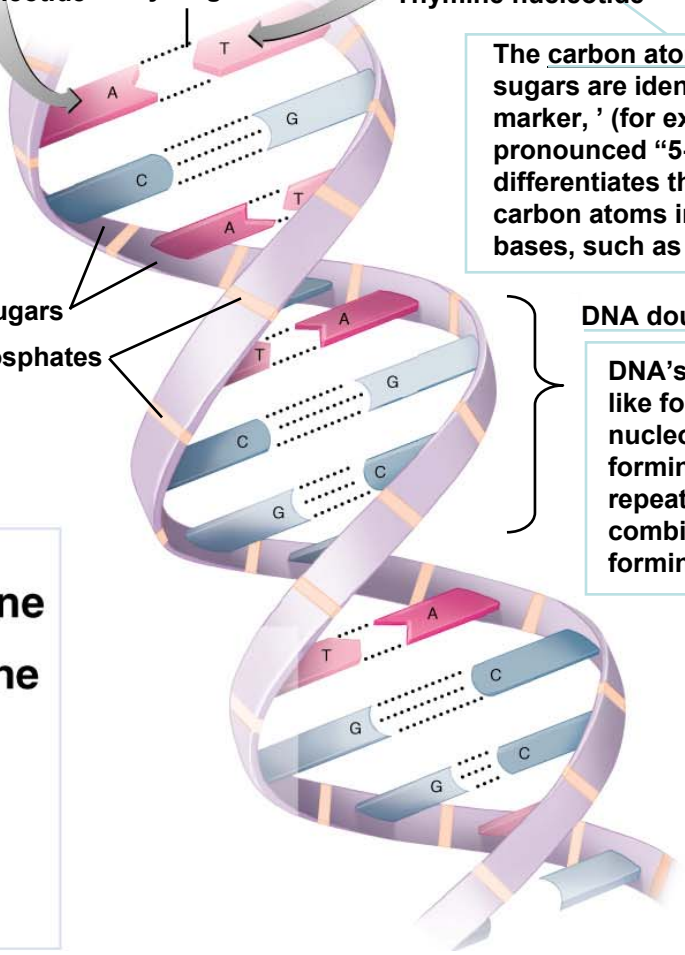
Adenine nucleotide

Hydrogen bonds

Thymine nucleotide

Individual DNA nucleotides are composed of a deoxyribose sugar molecule covalently bonded to a phosphate group at the 5' carbon, and to a nitrogen-containing base at the 3' carbon. The two nucleotides shown here are held together by hydrogen bonds.

The carbon atoms in the sugars are identified by adding a marker, ' (for example, 5', pronounced "5-prime"). This differentiates them from the carbon atoms in the nucleo-bases, such as Thymine.



Sugar-phosphate backbone

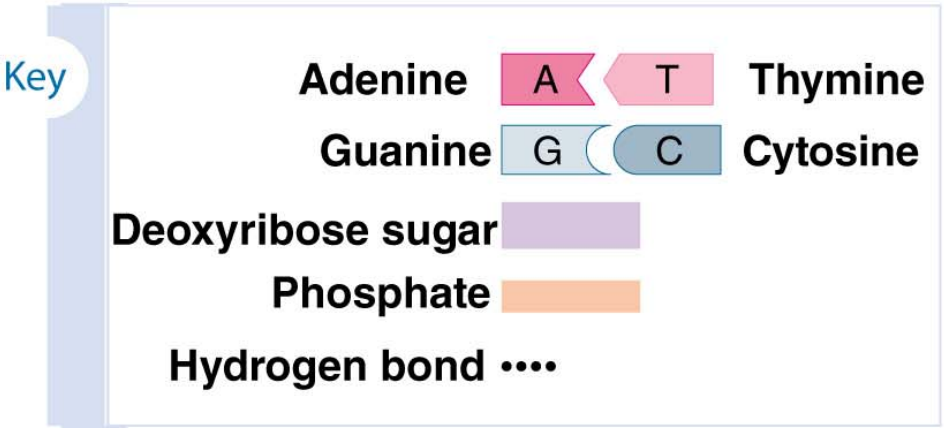
Sugars

Phosphates

The sugar-phosphate backbone of one strand is upside down, or antiparallel, relative to the backbone of the other strand.

DNA double helix

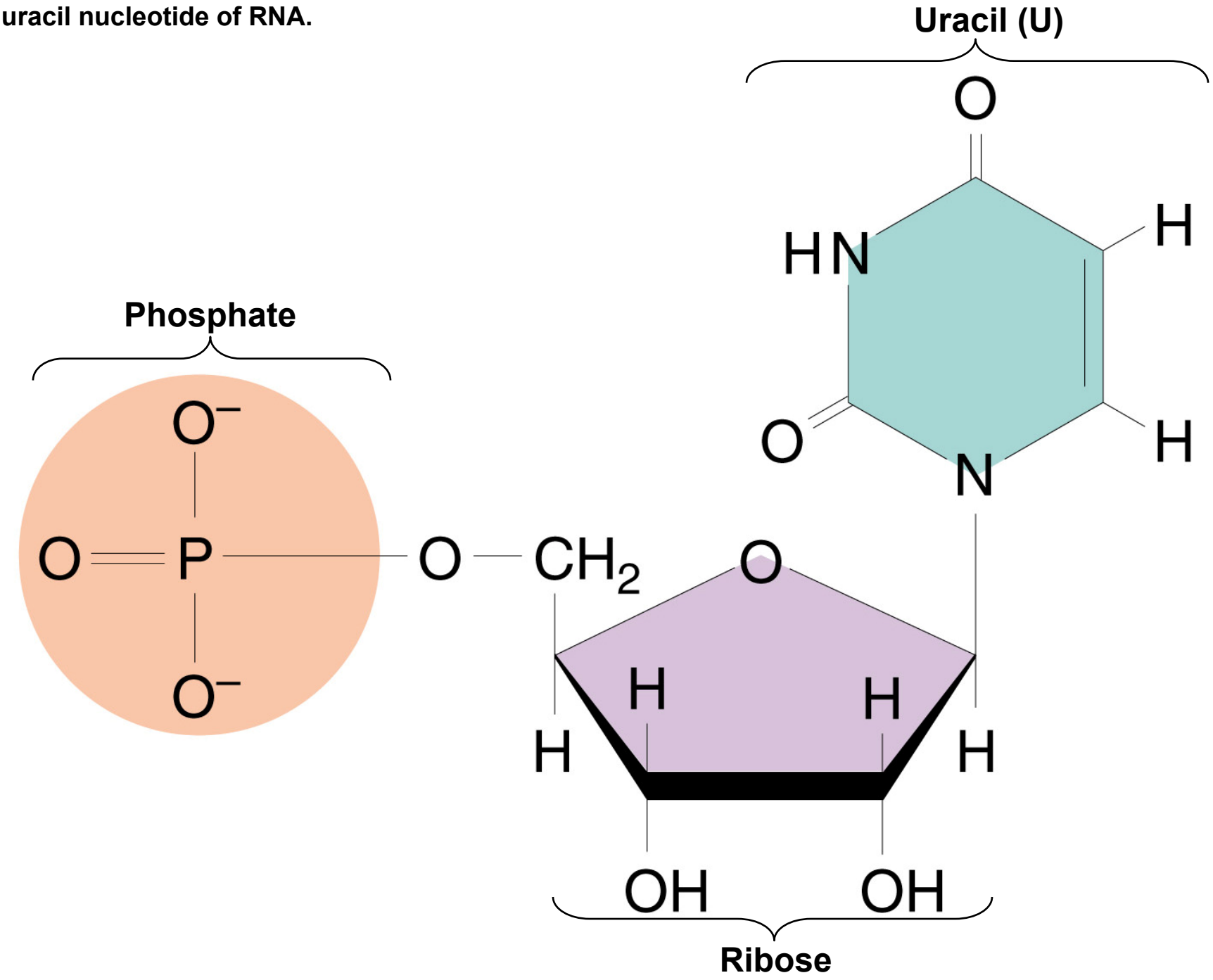
DNA's double-helical, ladder-like form is made up of many nucleotides base pairs forming the rungs, and the repeating sugar-phosphate combination, forming the backbone.



RNA

- **Ribonucleic acid**
- Has ribose
- Is single-stranded
- **A** hydrogen bonds with **U**
- **C** hydrogen bonds with **G**

A uracil nucleotide of RNA.

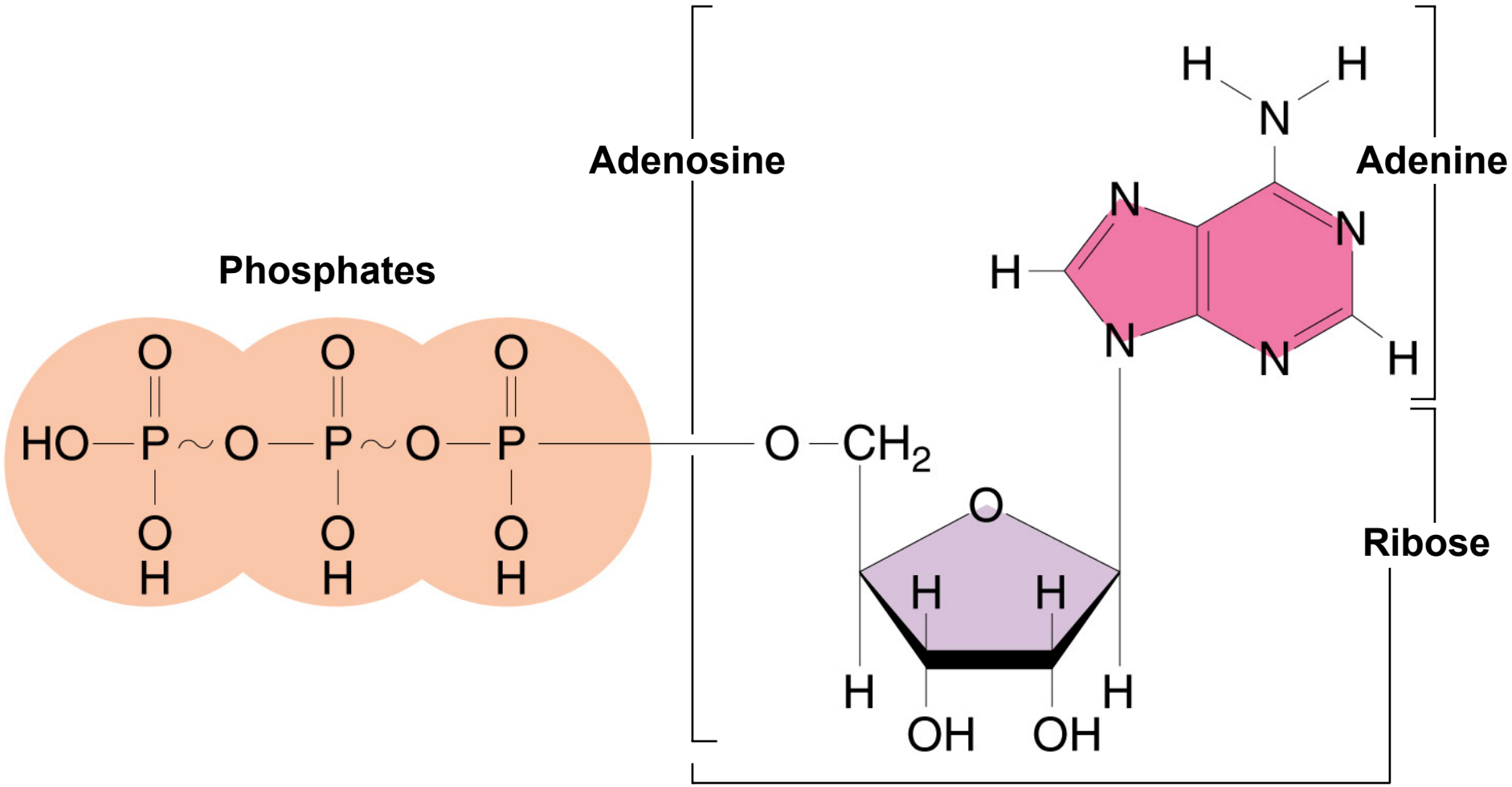


ATP

- **Adenosine triphosphate**

- Has ribose, adenine, and three phosphate groups

The structure of ATP.



ATP

- Is made by dehydration synthesis
- Is broken by hydrolysis to liberate useful energy for the cell