CHAPTER 2

The Chemical Level of Organization
Chapter 2 Learning Outcomes

• 2-1
  • Describe an atom and how atomic structure affects interactions between atoms.

• 2-2
  • Compare the ways in which atoms combine to form molecules and compounds.

• 2-3
  • Use chemical notation to symbolize chemical reactions, and distinguish among the three major types of chemical reactions that are important for studying physiology.

• 2-4
  • Describe the crucial role of enzymes in metabolism.
Chapter 2 Learning Outcomes

• 2-5
  • Distinguish between organic and inorganic compounds.
• 2-6
  • Explain how the chemical properties of water make life possible.
• 2-7
  • Describe the pH scale and the role of buffers in body fluids.
• 2-8
  • Describe the functional roles of inorganic compounds.
• 2-9
  • Discuss the structures and functions of carbohydrates.
• 2-10
  • Discuss the structures and functions of lipids.
Chapter 2 Learning Outcomes

• 2-11
  • Discuss the structures and functions of proteins.
• 2-12
  • Discuss the structures and functions of nucleic acids.
• 2-13
  • Discuss the structures and functions of high-energy compounds.
• 2-14
  • Explain the relationship between chemicals and cells.
Atoms: The Basic Particles of Matter (2-1)

- Matter
  - Anything that takes up space and has mass
  - Composed of elements (e.g., oxygen, sodium)
  - Smallest, stable unit of matter is the atom
Atoms contain three major subatomic particles

1. Protons (p⁺)
   - Have mass and a positive electrical charge
   - Found in the atom's nucleus

2. Neutrons (n or n⁰)
   - Have mass and are electrically neutral
   - Found in the atom's nucleus

3. Electrons (e⁻)
   - Have very little mass and have a negative electrical charge
   - Found orbiting around nucleus at high speed in electron cloud or shell
Figure 2-1  A Diagram of Atomic Structure.

Helium, He
Space-filling model. This space-filling model of a hydrogen atom depicts the three-dimensional electron cloud formed by the single orbiting electron.
Electron-shell model. In a two-dimensional electron-shell model, it is easier to visualize the atom’s components.
### Table 2-1 The Principal Elements in the Human Body

<table>
<thead>
<tr>
<th>Element</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxygen, O (65)</td>
<td>A component of water and other compounds; oxygen gas is essential for respiration</td>
</tr>
<tr>
<td>Carbon, C (18.6)</td>
<td>Found in all organic molecules</td>
</tr>
<tr>
<td>Hydrogen, H (9.7)</td>
<td>A component of water and most other compounds in the body</td>
</tr>
<tr>
<td>Nitrogen, N (3.2)</td>
<td>Found in proteins, nucleic acids, and other organic compounds</td>
</tr>
<tr>
<td>Calcium, Ca (1.8)</td>
<td>Found in bones and teeth; important for membrane function, nerve impulses, muscle contraction, and blood clotting</td>
</tr>
<tr>
<td>Phosphorus, P (1)</td>
<td>Found in bones and teeth, nucleic acids, and high-energy compounds</td>
</tr>
<tr>
<td>Potassium, K (0.4)</td>
<td>Important for membrane function, nerve impulses, and muscle contraction</td>
</tr>
<tr>
<td>Sodium, Na (0.2)</td>
<td>Important for membrane function, nerve impulses, and muscle contraction</td>
</tr>
<tr>
<td>Chlorine, Cl (0.2)</td>
<td>Important for membrane function and water absorption</td>
</tr>
<tr>
<td>Magnesium, Mg (0.06)</td>
<td>Required for activation of several enzymes</td>
</tr>
<tr>
<td>Sulfur, S (0.04)</td>
<td>Found in many proteins</td>
</tr>
<tr>
<td>Iron, Fe (0.007)</td>
<td>Essential for oxygen transport and energy capture</td>
</tr>
<tr>
<td>Iodine, I (0.0002)</td>
<td>A component of hormones of the thyroid gland</td>
</tr>
</tbody>
</table>
Atomic Number (2-1)

- The total of the number of protons and neutrons in the nucleus of the atom
- Atomic mass not affected by gravity
- An estimate of the atomic weight
Isotopes (2-1)

- Atoms of an element with different numbers of neutrons in the nucleus
- Recognized by their mass number, the total of protons and neutrons in the nucleus
- Unstable isotopes are radioactive
Atomic Weight (2-1)

- The *average mass* of an element's atoms
- Considers influence of isotopes' differences in mass
Electron Shells (2-1)

• Atoms are electrically neutral
  • Protons balance with electrons

• Electrons orbit nucleus in shells
  • Those in outer shell can interact with other atoms
Electron Shells (2-1)

• The number of electrons in an atom's outer shell:
  • Determines the chemical properties of that element

• Shells have finite number of possible electrons

• An atom with an outer shell that is "filled" is very stable, inert

• An atom with an outer shell that is not filled will react with other atoms
In a carbon atom, which has six protons and six electrons, the first shell is full, but the second shell contains only four electrons. In a neon atom, which has 10 protons and 10 electrons, both the first and second electron shells are filled. Notice that the nuclei of carbon and neon contain neutrons as well as protons.
Checkpoint (2-1)

1. Define atom.

2. How is it possible for two samples of hydrogen to contain the same number of atoms but have different weights?
Chemical Bonds (2-2)

- **Unstable atoms**
  - React with each other by sharing, gaining, or losing electrons in chemical bonds

- **Molecules**
  - Contain more than one atom bonded together by shared electrons

- **Compounds**
  - Are made up of two or more elements bonded together by any one of the kinds of chemical bonds
Ionic Bonds (2-2)

- Some atoms will gain or lose electrons in the outer shell to gain stability
  - Altering the atom's electric charge
- An atom that gains more electrons than it has protons:
  - Will be negatively charged and an anion (–)
- An atom that loses more electrons than it has protons:
  - Will be positively charged and a cation (+)
Ionic Bonds (2-2)

- Ionic compounds are formed by ionic bonds
- Cations and anions are electrically attracted to each other
**Figure 2-4 Ionic Bonding.**

1. **Formation of ions**
   - Sodium atom
   - Chlorine atom

2. **Attraction between opposite charges**
   - Sodium ion (Na\(^+\))
   - Chloride ion (Cl\(^-\))

3. **Formation of an ionic compound**
   - Sodium chloride (NaCl)

**Formation of an ionic bond.**

1. A sodium (Na) atom loses an electron, which is accepted by a chlorine (Cl) atom.  
2. Because the sodium (Na\(^+\)) and chloride (Cl\(^-\)) ions have opposite charges, they are attracted to one another.  
3. The association of sodium and chloride ions forms the ionic compound sodium chloride.

**Sodium chloride crystal.**
Large numbers of sodium and chloride ions form a crystal of sodium chloride (table salt).
Formation of an ionic bond. 1 A sodium (Na) atom loses an electron, which is accepted by a chlorine (Cl) atom. 2 Because the sodium (Na+) and chloride (Cl−) ions have opposite charges, they are attracted to one another. 3 The association of sodium and chloride ions forms the ionic compound sodium chloride.
Figure 2-4a Ionic Bonding. (1 of 3)

Formation of ions

Sodium atom

Chlorine atom
Attraction between opposite charges

Sodium ion (Na\(^+\))

Chloride ion (Cl\(^-\))
Formation of an ionic compound

Sodium chloride (NaCl)
Large numbers of sodium and chloride ions form a crystal of sodium chloride (table salt).
<table>
<thead>
<tr>
<th>Cations</th>
<th>Anions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na⁺ (sodium)</td>
<td>Cl⁻ (chloride)</td>
</tr>
<tr>
<td>K⁺ (potassium)</td>
<td>HCO₃⁻ (bicarbonate)</td>
</tr>
<tr>
<td>Ca²⁺ (calcium)</td>
<td>HPO₄²⁻ (biphosphate)</td>
</tr>
<tr>
<td>Mg²⁺ (magnesium)</td>
<td>SO₄²⁻ (sulfate)</td>
</tr>
</tbody>
</table>
Covalent Bonds (2-2)

- Sharing of electrons between atoms

  **Single covalent bond**
  - Sharing of one pair of electrons

  **Double covalent bond**
  - Sharing of two pairs of electrons

- Covalent bonds are relatively stable and strong
Figure 2-5 Covalent Bonds in Three Common Molecules.

<table>
<thead>
<tr>
<th>Molecule</th>
<th>Electron Shell Model and Structural Formula</th>
<th>Space-filling Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen (H₂)</td>
<td><img src="image1" alt="Electron Shell Model" /> H-H</td>
<td><img src="image2" alt="Space-filling Model" /></td>
</tr>
<tr>
<td>Oxygen (O₂)</td>
<td><img src="image3" alt="Electron Shell Model" /> O=O</td>
<td><img src="image4" alt="Space-filling Model" /></td>
</tr>
<tr>
<td>Carbon dioxide (CO₂)</td>
<td><img src="image5" alt="Electron Shell Model" /> O=C=O</td>
<td><img src="image6" alt="Space-filling Model" /></td>
</tr>
</tbody>
</table>
Covalent Bonds (2-2)

• **Nonpolar covalent bonds**
  - Electrons shared equally

• **Polar covalent bonds**
  - One element holds a shared electron more strongly than the other, or sharing is unequal
  - They form polar molecules

• **Polar molecules**
  - Will have a slight negative on one end of the molecule, a slight positive on the other end
Hydrogen Bonds (2-2)

- Too weak to create molecules
- An attraction between:
  - A slight positive charge on the hydrogen atom of a polar covalent bond
  - And a slight negative charge on an oxygen or nitrogen atom of another polar covalent bond
The unequal sharing of electrons in a water molecule causes each of its two hydrogen atoms to have a slight positive charge and its oxygen atom to have a slight negative charge. Attraction between a hydrogen atom of one water molecule and the oxygen atom of another is a hydrogen bond (indicated by dashed lines).

Hydrogen bonding between water molecules at a free surface creates surface tension and slows evaporation.
3. Define chemical bond, and identify several types of chemical bonds.

4. Oxygen and neon are both gases at room temperature. Why does oxygen readily combine with other elements, but neon does not?

5. Which kind of bond holds atoms in a water molecule together? What attracts water molecules to each other?
Types of Chemical Reactions (2-3)

• Three key chemical reactions in physiology
  1. Decomposition reactions
  2. Synthesis reactions
  3. Exchange reactions

• Reactants
  • Are rearranged to form products

• Metabolism
  • Is the sum of all chemical reactions in the body
Energy (2-3)

- The capacity to do work
  - **Kinetic energy**
    - Energy of motion
  - **Potential energy**
    - Stored energy
  - Energy can be converted from one form to another
    - Heat is a by-product of this conversion
**FIGURE 2-7 Chemical Notation**

**VISUAL REPRESENTATION**

**Atoms**
- One atom of hydrogen: \( \text{H} \)
- One atom of oxygen: \( \text{O} \)
- Two atoms of hydrogen: \( \text{H}_2 \)
- Two atoms of oxygen: \( \text{O}_2 \)

**Molecules**
- Hydrogen molecule composed of two hydrogen atoms: \( \text{H}_2 \)
- Oxygen molecule composed of two oxygen atoms: \( \text{O}_2 \)
- Water molecule composed of two hydrogen atoms and one oxygen atom: \( \text{H}_2\text{O} \)

**Reactions**
- Balanced equation: \( 2\text{H} + \text{O} \rightarrow \text{H}_2\text{O} \)
- Unbalanced equation: \( 2\text{H} + 2\text{O} \rightarrow \text{H}_2\text{O} \)

**Ions**
- Sodium ion: \( \text{Na}^+ \)
- Chloride ion: \( \text{Cl}^- \)
- Calcium ion: \( \text{Ca}^{2+} \)

**A sodium atom becomes a sodium ion**
- Sodium atom (Na) becomes a sodium ion (Na\(^+\)).
- Electron lost: Na → Na\(^+\)
VISUAL REPRESENTATION

Atoms

- H
  one atom of hydrogen
- H H
  two atoms of hydrogen

- O
  one atom of oxygen
- O O
  two atoms of oxygen

CHEMICAL NOTATION

H
one atom of hydrogen
O
one atom of oxygen

2H
two atoms of hydrogen
2O
two atoms of oxygen
Molecules

Hydrogen molecule composed of two hydrogen atoms

Oxygen molecule composed of two oxygen atoms

Water molecule composed of two hydrogen atoms and one oxygen atom

Chemical Notation

H₂ hydrogen molecule
O₂ oxygen molecule
H₂O water molecule
**VISUAL REPRESENTATION**

Reactions

**CHEMICAL NOTATION**

\[ 2H + O \rightarrow H_2O \]
Balanced equation

\[ 2H + 2O \rightarrow H_2O \]
Unbalanced equation
Figure 2-7 Chemical Notation (4 of 4)

VISUAL REPRESENTATION

Ions

- Sodium ion: the sodium atom has lost one electron
- Chloride ion: the chlorine atom has gained one electron
- Calcium ion: the calcium atom has lost two electrons

CHEMICAL NOTATION

Na⁺, Cl⁻, Ca²⁺

sodium ion, chloride ion, calcium ion

A sodium atom becomes a sodium ion

Electron lost
Sodium atom (Na) → Sodium ion (Na⁺)
Decomposition Reactions (2-3)

• Break a molecule into smaller parts
  
  • $AB \rightarrow A + B$

• In the body, these are often *hydrolysis* reactions
  
  • $A-B + H_2O \rightarrow A-H + HO-B$

• **Catabolism**
  
  • Decomposition reactions in the body, releasing kinetic energy for work
Synthesis Reactions (2-3)

- Make larger molecules from small parts
  - $\text{A + B} \rightarrow \text{AB}$

- Dehydration synthesis
  - Forms a complex molecule by the removal of water
  - $\text{A—H + HO—B} \rightarrow \text{A—B} + \text{H}_2\text{O}$

- Anabolism
  - Builds storage molecules in body
Exchange Reactions (2-3)

• A shuffling of parts of molecules

  • $AB + CD \rightarrow AD + CB$

• A decomposition reaction followed by a synthesis reaction
Reversible Reactions (2-3)

- Symbolized by two opposite arrows
  
  \[ A + B \rightleftharpoons AB \]

- At chemical reaction \textit{equilibrium}, the rates of the two reactions are in balance
6. Using the rules for chemical notation, write the molecular formula for glucose, a compound composed of 6 carbon atoms, 12 hydrogen atoms, and 6 oxygen atoms.

7. Identify and describe three types of chemical reactions important to human physiology.

8. In living cells, glucose, a six-carbon molecule, is converted into two three-carbon molecules. What type of chemical reaction is this?
9. If the product of a reversible reaction is continuously removed, what will be the effect on the equilibrium?
Enzymes (2-4)

- Aid in chemical reactions
- Lower the **activation energy**
  - The amount of energy required to start a reaction
- Act as **catalysts** to speed the rate of reactions
  - But are not changed by reactions
Figure 2-8 The Effect of Enzymes on Activation Energy.

Energy

Reactants

Activation energy required

Without enzyme

With enzyme

Stable product

Progress of reaction

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Exergonic and Endergonic Reactions (2-4)

- **Exergonic** reactions
  - Release net energy because it took less to activate the reaction than what was released

- **Endergonic** reactions
  - Absorb net energy because it took more energy to activate the reactions

- Most reactions in body are exergonic
  - Generating heat to keep us warm
Checkpoint (2-4)

11. What is an enzyme?

12. Why are enzymes needed in our cells?
Inorganic and Organic Compounds (2-5)

- **Nutrients**
  - Essential elements and molecules obtained from the diet

- **Metabolites**
  - Chemicals that come from catabolism and anabolism in our bodies

- **Inorganic compounds**
  - Small, usually without carbon and hydrogen

- **Organic compounds**
  - Generally large and complex, made of carbon and hydrogen
12. Distinguish between inorganic and organic compounds.
Three Properties of Water (2-6)

1. Water is an essential reactant in the chemical reactions of living systems

2. Water has a very high heat capacity

3. Water is an excellent solvent
Water (2-6)

- **Solutions**
  - A mixture of a fluid *solvent* and dissolved *solute*

- **Dissociation or ionization**
  - Occurs when ionic compounds break apart into their charged ions in water
  - An organic molecule is soluble when it contains polar covalent bonds
Water molecule. In a water molecule, oxygen forms polar covalent bonds with two hydrogen atoms. Because both hydrogen atoms are at one end of the molecule, it has an uneven distribution of charges, creating positive and negative poles.
**Sodium chloride in solution.** Ionic compounds, such as sodium chloride, dissociate in water as the polar water molecules break the ionic bonds. Each ion remains in solution because it is surrounded by a sphere of water molecules.
Glucose in solution. Water molecules are also attracted to an organic molecule containing polar covalent bonds. If the molecule binds water strongly, as does glucose, it will be carried into solution—in other words, it will dissolve. Note that the molecule does not dissociate, as occurs for ionic compounds.
13. List the chemical properties of water that make life possible.

14. Why does water resist changes in temperature?
pH of Body Fluids (2-7)

- A hydrogen atom that loses its electron becomes a hydrogen ion, $\text{H}^+$
- $\text{H}^+$ is very reactive and can break important chemical bonds
- The concentration of $\text{H}^+$ in the body must be narrowly maintained within a normal pH
pH of Body Fluids (2-7)

• pH = $\frac{1}{\log [H^+]}$
  
  • The higher the concentration of $H^+$, the lower the pH

• The pH scale runs from 0–14
  
  • 7 is neutral

• A solution with a pH below 7 is *acidic*

• A solution with a pH above 7 is *alkaline*
Figure 2-10  pH and Hydrogen Ion Concentration.

- Increasing concentration of H⁺ ions
  - Stomach hydrochloric acid
  - Beer, vinegar, wine, pickles
  - Tomatoes, grapes
  - Urine
  - Saliva, milk
  - Blood
  - Pure water
  - Eggs
  - Ocean water
  - Household bleach
  - Household ammonia
  - Oven cleaner

- Decreasing concentration of OH⁻ ions

- Increasing concentration of OH⁻ ions
  - Extremely basic

- Decreasing concentration of H⁺ ions
  - Extremely acidic

pH scale from 0 to 14

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15. Define pH, and explain how the pH scale relates to acidity and alkalinity.

16. Why is an extreme change in pH of body fluids undesirable?
Acids, Bases, and Salts (2-8)

- Inorganic compounds
- Dissociated in water into ionic forms
Acids (2-8)

• Dissociate into a cation that is always $\text{H}^+$ and an anion that is not $\text{OH}^-$

• The stronger the acid, the more dissociation occurs

  • The more free $\text{H}^+$ is present, the lower the pH

• A strong acid is $\text{HCl} \rightarrow \text{H}^+ + \text{Cl}^-$
Bases (2-8)

- Dissociate into a cation that is never H\(^+\) and an anion that is OH\(^-\)
- The stronger the base, the more dissociation occurs
  - The less free H\(^+\) is present, the higher the pH
- A strong base is \(\text{NaOH} \rightarrow \text{Na}^+ + \text{OH}^-\)
Salts (2-8)

- Ionic compound
- Dissociate into a cation that is never $H^+$ and an anion that is never $OH^-$
- Table salt (NaCl)
  - In solution dissociates into $Na^+$ and $Cl^-$ ions
- Dissociation of salts makes a solution:
  - Slightly acidic or slightly basic
- Examples of electrolytes
  - Inorganic compounds whose ions conduct an electrical current in solution
Buffers and pH (2-8)

- **Buffer** systems
  - In the body maintain blood pH in a homeostatic range of 7.35–7.45
  - Stabilize pH by taking $\text{H}^+$ out of solution or dropping $\text{H}^+$ into solution
17. Define the following terms: acid, base, and salt.

18. How does an antacid decrease stomach discomfort?
Carbohydrates (2-9)

- Organic compounds with carbon, hydrogen, and oxygen in a ratio near 1:2:1
- Include sugars and starches
- A good source of energy
- Three major types
  1. Monosaccharides
  2. Disaccharides
  3. Polysaccharides
Monosaccharides (2-9)

- Simple sugars
- Building blocks for larger carbohydrates
- Dissolve readily in water
- **Glucose** is most important energy source in body
The structural formula of the straight-chain form of glucose.

The structural formula of the ring form, the most common form of glucose.

An abbreviated diagram of the ring form of glucose. In such carbon-ring diagrams, atoms attached to the ring are omitted, and only the symbols for elements other than carbon are shown.
Disaccharides and Polysaccharides (2-9)

• Disaccharides
  • Sucrose, maltose, lactose
  • Two monosaccharides linked by covalent bonds

• Polysaccharides
  • Starch, glycogen
  • Multiple monosaccharides and/or disaccharides linked by covalent bonds

• Bonds are broken through hydrolysis reactions
• Bonds are formed through dehydration synthesis
19. A food contains organic molecules with the elements C, H, and O in a ratio of 1:2:1. What class of compounds do the molecules represent, and what are their major functions in the body?

20. When two monosaccharides undergo a dehydration synthesis reaction, which type of molecule is formed?
Lipids (2-10)

- Contain a carbon-to-hydrogen ratio of 1:2
- May contain a variety of other elements
- Include fats, oils, and waxes
- Most are insoluble in water, but can be carried in the blood
- Used for long-term energy supplies
Fatty Acids (2-10)

- Long chains of carbon with a *carboxyl group*, -COOH, at the end
- Carboxyl end can dissolve in water
- The carbon chain, or "tail" is fairly insoluble
- **Saturated** and **unsaturated** fatty acids
Lauric acid shows the basic structure of a fatty acid: a long chain of carbon atoms and a carboxyl group (—COOH) at one end.

Lauric acid (C\textsubscript{12}H\textsubscript{24}O\textsubscript{2})
A fatty acid is either saturated (has single covalent bonds only) or unsaturated (has one or more double covalent bonds). The presence of a double bond causes a sharp bend in the molecule.
Fats (2-10)

• Use fatty acids attached to **glycerol** to form **triglycerides**
  • Most common fats in the body
Figure 2-14 Triglyceride Formation.

Glycerol

Fatty acids

Fatty Acid 1

Fatty Acid 2

Fatty Acid 3

Saturated

Saturated

Unsaturated

DEHYDRATION

SYNTHESIS

HYDROLYSIS

Triglyceride
Steroids (2-10)

- Large compounds of four connected rings of carbon
- **Cholesterol** is the most common
Figure 2-15  A Cholesterol Molecule.
Phospholipids (2-10)

- Contains glycerol, two fatty acids, a phosphate group, and a nonlipid group
- Nonlipid group is soluble in water
  - Fatty acid tails are fairly insoluble
- Most abundant lipid component in cell membranes
Figure 2-16 A Phospholipid Molecule.
### Table 2-4  Representative Lipids and Their Functions in the Body

<table>
<thead>
<tr>
<th>Lipid Type</th>
<th>Examples</th>
<th>Primary Functions</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatty Acids</td>
<td>Lauric acid</td>
<td>Energy sources</td>
<td>Absorbed from food or synthesized in cells; transported in the blood for use in many tissues</td>
</tr>
<tr>
<td>Fats</td>
<td>Monoglycerides, diglycerides, triglycerides</td>
<td>Energy source, energy storage, insulation, and physical protection</td>
<td>Stored in fat deposits; must be broken down to fatty acids and glycerol before they can be used as an energy source</td>
</tr>
<tr>
<td>Steroids</td>
<td>Cholesterol</td>
<td>Structural component of cell membranes, hormones, digestive secretions in bile</td>
<td>All have the same carbon-ring framework</td>
</tr>
<tr>
<td>Phospholipids</td>
<td>Lecithin</td>
<td>Structural components of cell membranes</td>
<td>Composed of fatty acids and nonlipid molecules</td>
</tr>
</tbody>
</table>

22. Which kind of lipid would be found in a sample of fatty tissue taken from beneath the skin?

23. Which lipids would you find in human cell membranes?
Seven key functions of proteins in the body

1. Support
2. Movement
3. Transport
4. Buffering
5. Metabolic regulation
6. Coordination and control
7. Defense
Protein Structure (2-11)

- Long chains of **amino acids**
- 20 different amino acids in the body

**Amino acids contain:**
- A central carbon atom bound to a hydrogen atom
- An amino group (—NH$_2$)
- A carboxyl group (—COOH)
- A side chain of varying lengths

- Amino acids are connected with **peptide bonds**
Each amino acid consists of a central carbon atom to which four different groups are attached: a hydrogen atom, an amino group ($\text{–NH}_2$), a carboxyl group ($\text{–COOH}$), and a variable group generally designated R.
Peptide Bond Formation

Peptides form when a dehydration synthesis reaction creates a peptide bond between the carboxyl group of one amino acid and the amino group of another. In this example, glycine (for which \( R = H \)) and alanine (for which \( R = CH_3 \)) are linked to form a dipeptide.

Figure 2-17b Amino Acids and the Formation of Peptide Bonds.
Protein Structure (2-11)

- Proteins are a function of the specific amino acid sequence
- R groups can interact to form a more complex protein
  - A globular protein
- The shape of the protein determines its function
- Proteins can undergo denaturation (a change in structure)
  - By changes in temperature, pH, and ionic composition
Enzyme Function (2-11)

- **Enzymes**
  - Essential proteins in the body that catalyze reactions

- **Reactants**
  - Referred to as *substrates*

- When substrates interact with enzymes, a *product* is formed

- **Enzymes** have an *active site*
  - Where substrates bind to undergo their reactions to form products

*ANIMATION Chemical Reactions: Enzymes*
Substrates bind to active site of enzyme.

Once bound to the active site, the substrates are held together, aiding their interaction.

Substrate binding alters the shape of the enzyme, and this change promotes product formation.

Product detaches from enzyme; entire process can now be repeated.

Substrates: $S_1$, $S_2$
Substrates bind to active site of enzyme.
Once bound to the active site, the substrates are held together, aiding their interaction.
Substrate binding alters the shape of the enzyme, and this change promotes product formation.
Product detaches from enzyme; entire process can now be repeated.
24. Describe a protein.

25. How does boiling a protein affect its structural and functional properties?
Nucleic Acids (2-12)

- Large organic molecules composed of:
  - Carbon, hydrogen, oxygen, nitrogen, and phosphorus
- Store and process information inside cells
- Two classes
  1. DNA—deoxyribonucleic acid
  2. RNA—ribonucleic acid
Structure of Nucleic Acids (2-12)

- Composed of strands of **nucleotides**
  - Nucleotides composed of:
    - A *sugar*
    - A *phosphate group*
    - A *nitrogenous base*
DNA (2-12)

- Is a double strand
  - Sugar is deoxyribose
  - Four nitrogenous bases
    1. Adenine (A)
    2. Guanine (G)
    3. Cytosine (C)
    4. Thymine (T)

PLAY ANIMATION Protein Synthesis: DNA Molecule
RNA (2-12)

- Is a single strand
  - Sugar is ribose
  - Four nitrogenous bases
    1. Adenine (A)
    2. Guanine (G)
    3. Cytosine (C)
    4. Uracil (U)
### Table 2-5 A Comparison of RNA and DNA

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>RNA</th>
<th>DNA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugar</td>
<td>Ribose</td>
<td>Deoxyribose</td>
</tr>
<tr>
<td>Nitrogenous Bases</td>
<td>Adenine</td>
<td>Adenine</td>
</tr>
<tr>
<td></td>
<td>Guanine</td>
<td>Guanine</td>
</tr>
<tr>
<td></td>
<td>Cytosine</td>
<td>Cytosine</td>
</tr>
<tr>
<td></td>
<td>Uracil</td>
<td>Thymine</td>
</tr>
<tr>
<td><strong>Number of Nucleotides in a Typical Molecule</strong></td>
<td>Varies from fewer than 100 nucleotides to about 50,000</td>
<td>Always more than 45 million nucleotides</td>
</tr>
<tr>
<td><strong>Shape of Molecule</strong></td>
<td>Single strand</td>
<td>Paired strands coiled in a double helix</td>
</tr>
<tr>
<td><strong>Function</strong></td>
<td>Performs protein synthesis as directed by DNA</td>
<td>Stores genetic information that controls protein synthesis</td>
</tr>
</tbody>
</table>
Figure 2-20a-b The Structure of Nucleic Acids.

**Nucleotide structure**

- Sugar
- Phosphate group
- Nitrogenous base

**Nitrogenous bases in nucleic acids**

- **A** Adenine
- **G** Guanine
- **C** Cytosine
- **T** Thymine (DNA only)
- **U** Uracil (RNA only)
**RNA molecule.** An RNA molecule has a single nucleotide chain. Its shape is determined by the sequence of nucleotides and by the interactions among them.

**DNA molecule.** A DNA molecule has a pair of nucleotide chains linked by hydrogen bonding between complementary base pairs.
26. Describe a nucleic acid.

27. A large organic molecule composed of ribose sugars, nitrogenous bases, and phosphate groups is which kind of nucleic acid?
ATP: The Energy Molecule (2-13)

- **High-energy compounds**
  - Made by attaching a phosphate group to an organic molecule

- **Adenosine triphosphate (ATP)**
  - Is the most important

- ATP is made with *adenosine monophosphate* (AMP) and two phosphate groups
  - By attaching a phosphate group to free ADP within the cells, ATP is generated
ATP: The Energy Molecule (2-13)

- Energy is stored by converting ADP to ATP
- The reverse releases energy

  - ADP + phosphate group + energy $\rightleftharpoons$ ATP + H$_2$O
Figure 2-21 The Structure of ATP.
Energy released for cellular activities

Energy from cellular catabolism

Figure 2-22 Energy Flow and the Recycling of ADP and ATP within Cells.
Organic Compounds

- Carbohydrates include:
  - Polysaccharides: composed of disaccharides and monosaccharides.
  - Disaccharides: composed of two monosaccharides.
  - Monosaccharides: contain glycerol.

- Lipids include:
  - Triglycerides: composed of fatty acids.
  - Fatty acids: contain disaccharides.

- Proteins include:
  - Peptides: composed of amino acids.
  - Amino acids: contain nucleotides.

- Nucleic Acids include:
  - RNA: composed of nucleotides.
  - DNA: composed of nucleotides.

- High-Energy Compounds include:
  - ATP: composed of nucleotides and phosphate groups.
28. Describe ATP.

29. What are the products of the hydrolysis of ATP?
Chemicals Combine to Make Cells (2-14)

• Combinations of:
  • Lipids, proteins, and some carbohydrates
  • Form structures that work together for a common purpose

• Each cell is a miniature organism
  • With structures built by biochemical building blocks
<table>
<thead>
<tr>
<th>Class</th>
<th>Building Blocks</th>
<th>Sources</th>
<th>Functions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>INORGANIC</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>Hydrogen and oxygen atoms</td>
<td>Absorbed as liquid water or generated by metabolism</td>
<td>Solvent; transport medium for dissolved materials and heat; cooling through evaporation; medium for chemical reactions; reactant in hydrolysis</td>
</tr>
<tr>
<td>Acids, bases, salts</td>
<td>$H^+$, $OH^-$, various anions and cations</td>
<td>Obtained from the diet or generated by metabolism</td>
<td>Structural components; buffers; sources of ions</td>
</tr>
<tr>
<td>Dissolved gases</td>
<td>Oxygen, carbon, nitrogen, and other atoms</td>
<td>Atmosphere</td>
<td>$O_2$: required for normal cellular metabolism</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$CO_2^-$: generated by cells as a waste product</td>
</tr>
<tr>
<td><strong>ORGANIC</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbohydrates</td>
<td>C, H, and O; CHO in a 1:2:1 ratio</td>
<td>Obtained from the diet or manufactured in the body</td>
<td>Energy source; some structural role when attached to lipids or proteins; energy storage</td>
</tr>
<tr>
<td>Lipids</td>
<td>C, H, O, sometimes N or P; CHO not in 1:2:1 ratio</td>
<td>Obtained from the diet or manufactured in the body</td>
<td>Energy source; energy storage; insulation; structural components; chemical messengers; protection</td>
</tr>
<tr>
<td>Proteins</td>
<td>C, H, O, N, often S</td>
<td>20 common amino acids; roughly half can be manufactured in the body, others must be obtained from the diet</td>
<td>Catalysts for metabolic reactions; structural components; movement; transport; buffers; defense; control and coordination of activities</td>
</tr>
<tr>
<td>Nucleic acids</td>
<td>C, H, O, N, and P; nucleotides composed of phosphates, sugars, and nitrogenous bases</td>
<td>Obtained from the diet or manufactured in the body</td>
<td>Storage and processing of genetic information</td>
</tr>
<tr>
<td>High-energy compounds</td>
<td>Nucleotides joined to phosphates by high-energy bonds</td>
<td>Synthesized by all cells</td>
<td>Storage or transfer of energy</td>
</tr>
</tbody>
</table>
29. Identify the biochemical building blocks that are the components of cells.