roughly half of undergraduate biology majors and biology Ph.D. students. The pace has been slow at higher levels in the profession, however, and women and many racial and ethnic groups are still significantly underrepresented in many branches of science. This lack of diversity hampers the progress of science. The more voices that are heard at the table, the more robust, valuable, and productive the scientific interchange will be. The authors of this text welcome all students to the community of biologists, wishing you the joys and satisfactions of this exciting field of science.

CONCEPT CHECK 1.4

1. How does science differ from technology?

2. **MAKE CONNECTIONS** The gene that causes sickle-cell disease is present in a higher percentage of residents of sub-Saharan Africa than among those of African descent living in the United States. This gene provides some protection from malaria, a serious disease that is widespread in sub-Saharan Africa. Discuss an evolutionary process that could account for the different percentages among residents of the two regions. (See Concept 1.2.)

For suggested answers, see Appendix A.

1 Chapter Review

**SUMMARY OF KEY CONCEPTS**

**CONCEPT 1.1**

The study of life reveals common themes (pp. 2–9)

**Organization Theme: New Properties Emerge at Successive Levels of Biological Organization**

- The hierarchy of life unfolds as follows: biosphere > ecosystem > community > population > organism > organ system > organ > tissue > cell > organelle > molecule > atom. With each step upward from atoms, new emergent properties result from interactions among components at the lower levels. In an approach called reductionism, complex systems are broken down to simpler components that are more manageable to study. In systems biology, scientists attempt to model the dynamic behavior of whole biological systems by studying the interactions among the system’s parts.

- The structure and function of biological components are interrelated. The cell, an organism’s basic unit of structure and function, is the lowest level of organization that can perform all activities required for life. Cells are either prokaryotic or eukaryotic. Eukaryotic cells contain membrane-enclosed organelles, including a DNA-containing nucleus. Prokaryotic cells lack membrane-enclosed organelles.

**Information Theme: Life’s Processes Involve the Expression and Transmission of Genetic Information**

- Genetic information is encoded in the nucleotide sequences of DNA. It is DNA that transmits heritable information from parents to offspring. DNA sequences called genes program a cell’s protein production by being transcribed into mRNAs and then translated into specific proteins, a process called gene expression. Gene expression also results in RNAs that are not translated into protein but serve other important functions. Genomics is the large-scale analysis of the DNA sequences of a species (its genome) as well as the comparison of genomes between species. Bioinformatics uses computational tools to deal with huge volumes of sequence data.

**Energy and Matter Theme: Life Requires the Transfer and Transformation of Energy and Matter**

- Energy flows through an ecosystem. All organisms must perform work, which requires energy. Producers convert energy from sunlight to chemical energy, some of which is then passed on to consumers. (The rest is lost as heat energy.) Chemicals cycle between organisms and the environment.

Johannes Gutenberg around 1440. This invention relied on several innovations from China, including paper and ink. Paper traveled along trade routes from China to Baghdad, where technology was developed for its mass production. This technology then migrated to Europe, as did water-based ink from China, which was modified by Gutenberg to become oil-based ink. We have the cross-fertilization of diverse cultures to thank for the printing press, and the same can be said for other important inventions.

Along similar lines, science stands to gain much from embracing a diversity of backgrounds and viewpoints among its practitioners. But just how diverse a population are scientists in relation to gender, race, ethnicity, and other attributes?

The scientific community reflects the cultural standards and behaviors of the society around it. It is therefore not surprising that until recently, women and certain minorities have faced huge obstacles in their pursuit to become professional scientists in many countries around the world. Over the past 50 years, changing attitudes about career choices have increased the proportion of women in biology and some other sciences, so that now women constitute roughly half of undergraduate biology majors and biology Ph.D. students. The pace has been slow at higher levels in the profession, however, and women and many racial and ethnic groups are still significantly underrepresented in many branches of science. This lack of diversity hampers the progress of science. The more voices that are heard at the table, the more robust, valuable, and productive the scientific interchange will be. The authors of this text welcome all students to the community of biologists, wishing you the joys and satisfactions of this exciting field of science.
Interactions Theme: From Ecosystems to Molecules, Interactions Are Important in Biological Systems
- Organisms interact continuously with physical factors. Plants take up nutrients from the soil and chemicals from the air and use energy from the sun. Interactions among plants, animals, and other organisms affect the participants in various ways.

- In feedback regulation, a process is regulated by its output or end product. In negative feedback, accumulation of the end product slows its production. In positive feedback, an end product speeds up its own production. Feedback is a type of regulation common to life at all levels, from molecules to ecosystems.

Evolution, the Core Theme of Biology
- Evolution, the process of change that has transformed life on Earth, accounts for the unity and diversity of life. It also explains evolutionary adaptation—the match of organisms to their environments.

- Darwin proposed natural selection as the mechanism for evolutionary adaptation of populations to their environments.

Science benefits from a cooperative approach and diverse viewpoints (pp. 21–24)
- Science is a social activity. The work of each scientist builds on the work of others that have come before. Scientists must be able to repeat each other’s results, so integrity is key. Biologists approach questions at different levels; their approaches complement each other.
- Technology consists of any method or device that applies scientific knowledge for some specific purpose that affects society. The ultimate impact of basic research is not always immediately obvious.
- Diversity among scientists promotes progress in science.

TEST YOUR UNDERSTANDING

LEVEL 1: KNOWLEDGE/COMPREHENSION
1. All the organisms on your campus make up
   a. an ecosystem.
   b. a community.
   c. a population.
   d. a taxonomic domain.
2. Which of the following is a correct sequence of levels in life’s hierarchy, proceeding downward from an individual animal?
   a. organism, brain, organ system, nerve cell
   b. organ system, nervous tissue, brain, nerve cell
   c. organism, organ system, tissue, cell, organ
   d. nervous system, brain, nervous tissue, nerve cell
SUMMARY OF KEY CONCEPTS

CONCEPT 2.1

Matter consists of chemical elements in pure form and in combinations called compounds (pp. 29–30)

- **Elements** cannot be broken down chemically to other substances. A **compound** contains two or more different elements in a fixed ratio. Oxygen, carbon, hydrogen, and nitrogen make up approximately 96% of living matter.

? In what way does the need for iodine or iron in your diet differ from your need for calcium or phosphorus?

CONCEPT 2.2

An element’s properties depend on the structure of its atoms (pp. 30–36)

- **An atom**, the smallest unit of an element, has the following components:

  ![Atom diagram](image)

  - Nucleus
  - Protons (+ charge) determine element
  - Neutrons (no charge) determine isotope
  - Electrons (– charge) form negative cloud and determine chemical behavior

- An electrically neutral atom has equal numbers of electrons and protons; the number of protons determines the atomic number. The atomic mass is measured in daltons and is roughly equal to the mass number, the sum of protons plus neutrons. **Isotopes** of an element differ from each other in neutron number and therefore mass. Unstable isotopes give off particles and energy as radioactivity.

- In an atom, electrons occupy specific **electron shells**; the electrons in a shell have a characteristic energy level. Electron distribution in shells determines the chemical behavior of an atom. An atom that has an incomplete outer shell, the valence shell, is reactive.

- Electrons exist in **orbitals**, three-dimensional spaces with specific shapes that are components of electron shells.

**DRAW IT** Draw the electron distribution diagrams for neon (\(\text{Ne}\)) and argon (\(\text{Ar}\)). Use these diagrams to explain why these elements are chemically unreactive.

CONCEPT 2.3

The formation and function of molecules depend on chemical bonding between atoms (pp. 36–40)

- **Chemical bonds** form when atoms interact and complete their valence shells. **Covalent bonds** form when pairs of electrons are shared.

  ![Covalent bond diagram](image)

  - Single covalent bond
  - Double covalent bond

- **Molecules** consist of two or more covalently bonded atoms. The attraction of an atom for the electrons of a covalent bond is its electronegativity. If both atoms are the same, they have the same electronegativity and share a **nonpolar covalent bond**. Electrons of a **polar covalent bond** are pulled closer to the more electronegative atom.

- An **ion** forms when an atom or molecule gains or loses an electron and becomes charged. An **ionic bond** is the attraction between two oppositely charged ions.

- **Weak bonds** reinforce the shapes of large molecules and help molecules adhere to each other. A **hydrogen bond** is an attraction between a hydrogen atom carrying a partial positive charge (\(\delta^+\)) and an electronegative atom (\(\delta^-\)). **Van der Waals interactions** occur between transiently positive and negative regions of molecules.

- A molecule’s shape is determined by the positions of its atoms’ valence orbitals. Covalent bonds result in hybrid orbitals, which are responsible for the shapes of \(\text{H}_2\text{O}\), \(\text{CH}_4\), and many more complex biological molecules. Shape is usually the basis for the recognition of one biological molecule by another.

? In terms of electron sharing between atoms, compare nonpolar covalent bonds, polar covalent bonds, and the formation of ions.

CONCEPT 2.4

Chemical reactions make and break chemical bonds (pp. 40–41)

- **Chemical reactions** change **reactants** into **products** while conserving matter. All chemical reactions are theoretically reversible. **Chemical equilibrium** is reached when the forward and reverse reaction rates are equal.

? What would happen to the concentration of products if more reactants were added to a reaction that was in chemical equilibrium? How would this addition affect the equilibrium?

TEST YOUR UNDERSTANDING

**LEVEL 1: KNOWLEDGE/COMPREHENSION**

1. In the term **trace element**, the adjective **trace** means that
   a. the element is required in very small amounts.
   b. the element can be used as a label to trace atoms through an organism’s metabolism.
   c. the element is very rare on Earth.
   d. the element enhances health but is not essential for the organism’s long-term survival.
Interpreting a Scatter Plot with a Regression Line

How Does the Carbonate Ion Concentration of Seawater Affect the Calcification Rate of a Coral Reef? Scientists predict that acidification of the ocean due to higher levels of atmospheric CO₂ will lower the concentration of dissolved carbonate ions, which living corals use to build calcium carbonate reef structures. In this exercise, you will analyze data from a controlled experiment that examined the effect of carbonate ion concentration ([CO₃²⁻]) on calcium carbonate deposition, a process called calcification.

How the Experiment Was Done The Biosphere 2 aquarium in Arizona contains a large coral reef system that behaves like a natural reef. For several years, a group of researchers measured the rate of calcification by the reef organisms and examined how the calcification rate changed with differing amounts of dissolved carbonate ions in the seawater.

Data from the Experiment The black data points in the graph form a scatter plot. The red line, known as a linear regression line, is the best-fitting straight line for these points.

Interpret the Data
1. When presented with a graph of experimental data, the first step in analysis is to determine what each axis represents. (a) In words, explain what is being shown on the x-axis. Be sure to include the units. (b) What is being shown on the y-axis (including units)? (c) Which variable is the independent variable—the variable that was manipulated by the researchers? (d) Which variable is the dependent variable—the variable that responded to or depended on the treatment, which was measured by the researchers? (For additional information about graphs, see the Scientific Skills Review in Appendix F and in the Study Area in MasteringBiology.)
2. Based on the data shown in the graph, describe in words the relationship between carbonate ion concentration and calcification rate.
3. (a) If the seawater carbonate ion concentration is 270 μmol/kg, what is the approximate rate of calcification, and approximately how many days would it take 1 square meter of reef to accumulate 30 mmol of calcium carbonate (CaCO₃)? (b) If the seawater carbonate ion concentration is 250 μmol/kg, what is the approximate rate of calcification, and approximately how many days would it take 1 square meter of reef to accumulate 30 mmol of calcium carbonate? (c) If carbonate ion concentration decreases, how does the calcification rate change, and how does that affect the time it takes coral to grow?
4. (a) Referring to the equations in Figure 3.11, determine which step of the process is measured in this experiment. (b) Are the results of this experiment consistent with the hypothesis that increased atmospheric CO₂ will slow the growth of coral reefs? Why or why not?

A version of this Scientific Skills Exercise can be assigned in MasteringBiology.


Chapter Review

SUMMARY OF KEY CONCEPTS

CONCEPT 3.1
Polar covalent bonds in water molecules result in hydrogen bonding (p. 45)
- Water is a polar molecule. A hydrogen bond forms when the slightly negatively charged oxygen of one water molecule is attracted to the slightly positively charged hydrogen of a nearby water molecule. Hydrogen bonding between water molecules is the basis for water’s properties.

DRAW IT Label a hydrogen bond and a polar covalent bond in this figure. Is a hydrogen bond a covalent bond? Explain.

CONCEPT 3.2
Four emergent properties of water contribute to Earth’s suitability for life (pp. 45–50)
- Hydrogen bonding keeps water molecules close to each other, and this cohesion helps pull water upward in the microscopic water-conducting cells of plants. Hydrogen bonding is also responsible for water’s surface tension.
- Water has a high specific heat. Heat is absorbed when hydrogen bonds break and is released when hydrogen bonds form. This helps keep temperatures relatively steady, within limits that permit life. Evaporative cooling is based on water’s high heat of vaporization. The evaporative loss of the most energetic water molecules cools a surface.
- Ice floats because it is less dense than liquid water. This property allows life to exist under the frozen surfaces of lakes and polar seas.
- Water is an unusually versatile solvent because its polar molecules are attracted to ions and polar substances that can form
Carbon and the Molecular Diversity of Life

Figure 4.1 What properties make carbon the basis of all life?

Carbon: The Backbone of Life

Living organisms, such as the plants and the Qinling golden snub-nosed monkeys shown in Figure 4.1, are made up of chemicals based mostly on the element carbon. Carbon enters the biosphere through the action of plants and other photosynthetic organisms. Plants use solar energy to transform atmospheric CO\(_2\) into the molecules of life, which are then taken in by plant-eating animals.

Of all the chemical elements, carbon is unparalleled in its ability to form molecules that are large, complex, and varied, making possible the diversity of organisms that have evolved on Earth. Proteins, DNA, carbohydrates, and other molecules that distinguish living matter from inanimate material are all composed of carbon atoms bonded to one another and to atoms of other elements. Hydrogen (H), oxygen (O), nitrogen (N), sulfur (S), and phosphorus (P) are other common ingredients of these compounds, but it is the element carbon (C) that accounts for the enormous variety of biological molecules.

Large biological molecules, such as proteins, are the main focus of Chapter 5. In this chapter, we investigate the properties of smaller molecules. We will use these small molecules to illustrate concepts of molecular architecture that will help explain why carbon is so important to life, at the same time highlighting the theme that emergent properties arise from the organization of matter in living organisms.
Is polar due to electronegative oxygen. Forms hydrogen bonds with water, helping dissolve compounds such as sugars. Compound name: Alcohol (specific name usually ends in -ol)

Sugars with ketone groups are called ketoses; those with aldehydes are called aldoses. Compound name: Ketone (carbonyl group is within a carbon skeleton) or aldehyde (carbonyl group is at the end of a carbon skeleton)

Acts as an acid (can donate H\(^+\)) because the covalent bond between oxygen and hydrogen is so polar. Compound name: Carboxylic acid, or organic acid

Acts as a base; can pick up an H\(^+\) from the surrounding solution (water, in living organisms). Compound name: Amine

Two — SH groups can react, forming a “cross-link” that helps stabilize protein structure. Hair protein cross-links maintain the straightness or curliness of hair; in hair salons, permanent treatments break cross-links, then re-form them while the hair is in the desired shape. Compound name: Thiol

Contributes negative charge (1– when positioned inside a chain of phosphates; 2– when at the end). When attached, confers on a molecule the ability to react with water, releasing energy. Compound name: Organic phosphate

Affects the expression of genes when on DNA or on proteins bound to DNA. Affects the shape and function of male and female sex hormones. Compound name: Methylated compound

### Figure 4.9 Some biologically important chemical groups.

<table>
<thead>
<tr>
<th>Chemical Group</th>
<th>Group Properties and Compound Name</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydroxyl group (—OH)</td>
<td>Is polar due to electronegative oxygen. Forms hydrogen bonds with water, helping dissolve compounds such as sugars.</td>
<td>Ethanol, the alcohol present in alcoholic beverages</td>
</tr>
<tr>
<td>Carbonyl group ((\overset{\cdots}{\text{C}} \overset{\cdots}{\text{O}}))</td>
<td>Sugars with ketone groups are called ketoses; those with aldehydes are called aldoses.</td>
<td>Acetone, the simplest ketone, Propanal, an aldehyde</td>
</tr>
<tr>
<td>Carboxyl group (—COOH)</td>
<td>Acts as an acid (can donate H(^+)) because the covalent bond between oxygen and hydrogen is so polar.</td>
<td>Acetic acid, which gives vinegar its sour taste, Ionized form of —COOH (carboxylate ion), found in cells</td>
</tr>
<tr>
<td>Amino group (—NH(_2))</td>
<td>Acts as a base; can pick up an H(^+) from the surrounding solution (water, in living organisms).</td>
<td>Glycine, an amino acid (note its carboxyl group), Ionized form of —NH(_2), found in cells</td>
</tr>
<tr>
<td>Sulfhydryl group (—SH)</td>
<td>Two — SH groups can react, forming a “cross-link” that helps stabilize protein structure. Hair protein cross-links maintain the straightness or curliness of hair; in hair salons, permanent treatments break cross-links, then re-form them while the hair is in the desired shape.</td>
<td>Cysteine, a sulfur-containing amino acid</td>
</tr>
<tr>
<td>Phosphate group (—OPO(_3)^{2–}))</td>
<td>Contributions negative charge (1– when positioned inside a chain of phosphates; 2– when at the end). When attached, confers on a molecule the ability to react with water, releasing energy.</td>
<td>Glycerol phosphate, which takes part in many important chemical reactions in cells</td>
</tr>
<tr>
<td>Methyl group (—CH(_3))</td>
<td>Affects the expression of genes when on DNA or on proteins bound to DNA. Affects the shape and function of male and female sex hormones.</td>
<td>5-Methyl cytosine, a component of DNA that has been modified by addition of a methyl group</td>
</tr>
</tbody>
</table>
inorganic phosphate and ADP (adenosine diphosphate). This reaction releases energy that can be used by the cell.

\[
\text{ATP} \xrightarrow{\text{Reacts with } H_2O} \text{P}_i + \text{ADP} \xrightarrow{\text{Energy}} \text{Adenosine}
\]

7. In what ways do a methyl group differ chemically from the other six important chemical groups shown in Figure 4.9?

LEVEL 1: KNOWLEDGE/COMPREHENSION

1. Organic chemistry is currently defined as
   a. the study of compounds made only by living cells.
   b. the study of carbon compounds.
   c. the study of natural (as opposed to synthetic) compounds.
   d. the study of hydrocarbons.

2. Which functional group is \textit{not} present in this molecule?
   a. carboxyl
   b. sulphydryl
   c. hydroxyl
   d. amino

3. MAKE CONNECTIONS Which chemical group is most likely to be responsible for an organic molecule behaving as a base (see Concept 3.3)?
   a. hydroxyl
   b. carbonyl
   c. amino
   d. phosphate

LEVEL 2: APPLICATION/ANALYSIS

4. Which of the following hydrocarbons has a double bond in its carbon skeleton?
   a. \( \text{C}_3\text{H}_8 \)
   b. \( \text{C}_2\text{H}_6 \)
   c. \( \text{C}_2\text{H}_4 \)
   d. \( \text{C}_2\text{H}_2 \)

5. Choose the term that correctly describes the relationship between these two sugar molecules:
   a. structural isomers
   b. \textit{cis-trans} isomers
   c. enantiomers
   d. isotopes

6. Identify the asymmetric carbon in this molecule:

   \[
   \begin{array}{c}
   \text{O} \\
   \text{C} \\
   \text{H} \\
   \text{H} \\
   \text{H} \\
   \text{H} \\
   \text{H} \\
   \text{H} \\
   \end{array}
   \]

7. Which action could produce a carbonyl group?
   a. the replacement of the \(-\text{OH}\) of a carboxyl group with hydroxymethylene
   b. the addition of a thiol to a hydroxyl
   c. the addition of a hydroxyl to a phosphate
   d. the replacement of the nitrogen of an amine with oxygen

8. Which of the molecules shown in question 5 has an asymmetric carbon? Which carbon is asymmetric?

LEVEL 3: SYNTHESIS/EVALUATION

9. EVOLUTION CONNECTION
   DRAW IT Some scientists think that life elsewhere in the universe might be based on the element silicon, rather than on carbon, as on Earth. Look at the electron distribution diagram for silicon in Figure 2.7 and draw the Lewis dot structure for silicon. What properties does silicon share with carbon that would make silicon-based life more likely than, say, neon-based life or aluminum-based life?

10. SCIENTIFIC INQUIRY
   50 years ago, pregnant women who were prescribed thalidomide for morning sickness gave birth to children with birth defects. Thalidomide is a mixture of two enantiomers; one reduces morning sickness, but the other causes severe birth defects. Today, the FDA has approved this drug for non-pregnant individuals with Hansen’s disease (leprosy) or newly diagnosed multiple myeloma, a blood and bone marrow cancer. The beneficial enantiomer can be synthesized and given to patients, but over time, both the beneficial and the harmful enantiomer can be detected in the body. Propose a possible explanation for the presence of the harmful enantiomer.

11. WRITE ABOUT A THEME: ORGANIZATION
   In 1918, an epidemic of sleeping sickness caused an unusual rigid paralysis in some survivors, similar to symptoms of advanced Parkinson’s disease. Years later, \( \text{L}-\text{dopa} \) (below, left), a chemical used to treat Parkinson’s disease, was given to some of these patients. \( \text{L}-\text{dopa} \) was remarkably effective at eliminating the paralysis, at least temporarily. However, its enantiomer, \( \text{D}-\text{dopa} \) (right), was subsequently shown to have no effect at all, as is the case for Parkinson’s disease. In a short essay (100–150 words), discuss how the effectiveness of one enantiomer and not the other illustrates the theme of structure and function.

12. SYNTHESIZE YOUR KNOWLEDGE
   Explain how the chemical structure of the carbon atom accounts for the differences between the male and female lions seen in the photo.
### Nonpolar side chains; hydrophobic

<table>
<thead>
<tr>
<th>Side chain (R group)</th>
<th>Figure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glycine (Gly or G)</td>
<td><img src="image" alt="Glycine" /></td>
</tr>
<tr>
<td>Alanine (Ala or A)</td>
<td><img src="image" alt="Alanine" /></td>
</tr>
<tr>
<td>Valine (Val or V)</td>
<td><img src="image" alt="Valine" /></td>
</tr>
<tr>
<td>Leucine (Leu or L)</td>
<td><img src="image" alt="Leucine" /></td>
</tr>
<tr>
<td>Isoleucine (Ile or I)</td>
<td><img src="image" alt="Isoleucine" /></td>
</tr>
<tr>
<td>Methionine (Met or M)</td>
<td><img src="image" alt="Methionine" /></td>
</tr>
<tr>
<td>Phenylalanine (Phe or F)</td>
<td><img src="image" alt="Phenylalanine" /></td>
</tr>
<tr>
<td>Tryptophan (Trp or W)</td>
<td><img src="image" alt="Tryptophan" /></td>
</tr>
<tr>
<td>Proline (Pro or P)</td>
<td><img src="image" alt="Proline" /></td>
</tr>
</tbody>
</table>

### Polar side chains; hydrophilic

Since cysteine is only weakly polar, it is sometimes classified as a nonpolar amino acid.

<table>
<thead>
<tr>
<th>Side chain (R group)</th>
<th>Figure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Serine (Ser or S)</td>
<td><img src="image" alt="Serine" /></td>
</tr>
<tr>
<td>Threonine (Thr or T)</td>
<td><img src="image" alt="Threonine" /></td>
</tr>
<tr>
<td>Cysteine (Cys or C)</td>
<td><img src="image" alt="Cysteine" /></td>
</tr>
<tr>
<td>Tyrosine (Tyr or Y)</td>
<td><img src="image" alt="Tyrosine" /></td>
</tr>
<tr>
<td>Asparagine (Asn or N)</td>
<td><img src="image" alt="Asparagine" /></td>
</tr>
<tr>
<td>Glutamine (Gln or Q)</td>
<td><img src="image" alt="Glutamine" /></td>
</tr>
</tbody>
</table>

### Electrically charged side chains; hydrophilic

**Acidic** (negatively charged)

<table>
<thead>
<tr>
<th>Side chain (R group)</th>
<th>Figure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aspartic acid (Asp or D)</td>
<td><img src="image" alt="Aspartic acid" /></td>
</tr>
<tr>
<td>Glutamic acid (Glu or E)</td>
<td><img src="image" alt="Glutamic acid" /></td>
</tr>
</tbody>
</table>

**Basic** (positively charged)

<table>
<thead>
<tr>
<th>Side chain (R group)</th>
<th>Figure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lysine (Lys or K)</td>
<td><img src="image" alt="Lysine" /></td>
</tr>
<tr>
<td>Arginine (Arg or R)</td>
<td><img src="image" alt="Arginine" /></td>
</tr>
<tr>
<td>Histidine (His or H)</td>
<td><img src="image" alt="Histidine" /></td>
</tr>
</tbody>
</table>

---

**Figure 5.14** The 20 amino acids of proteins. The amino acids are grouped here according to the properties of their side chains (R groups) and shown in their prevailing ionic forms at pH 7.2, the pH within a cell. The three-letter and one-letter abbreviations for the amino acids are in parentheses. All of the amino acids used in proteins are L enantiomers (see Figure 4.7c).
Components of lipids vary. Monomers form larger molecules by dehydration reactions, in which water molecules are released. Polymers can disassemble by the reverse process, hydrolysis. An immense variety of polymers can be built from a small set of monomers.

What is the fundamental basis for the differences between large carbohydrates, proteins, and nucleic acids?

### SUMMARY OF KEY CONCEPTS

#### Concept 5.1

Macromolecules are polymers, built from monomers (pp. 67–68)
- Large carbohydrates (polysaccharides), proteins, and nucleic acids are **polymers**, which are chains of **monomers**.

#### Concept 5.2

Carbohydrates serve as fuel and building material (pp. 68–72)
- **Monosaccharides**: glucose, fructose
- **Disaccharides**: lactose, sucrose
- **Polysaccharides**:
  - Cellulose (plants)
  - Starch (plants)
  - Glycogen (animals)
  - Chitin (animals and fungi)

#### Concept 5.3

Lipids are a diverse group of hydrophobic molecules (pp. 72–75)
- **Triacylglycerols** (fats or oils): glycerol + 3 fatty acids
- **Phospholipids**: glycerol + phosphate group + 2 fatty acids
- **Steroids**: four fused rings with attached chemical groups

#### Concept 5.4

Proteins include a diversity of structures, resulting in a wide range of functions (pp. 75–84)
- Enzymes
- Structural proteins
- Hormones
- Receptor proteins
- Motor proteins
- Defensive proteins

#### Concept 5.5

Nucleic acids store, transmit, and help express hereditary information (pp. 84–87)
- **DNA**:
  - Sugar = deoxyribose
  - Nitrogenous bases = C, G, A, T
  - Usually double-stranded
- **RNA**:
  - Sugar = ribose
  - Nitrogenous bases = C, G, A, U
  - Usually single-stranded

What role does complementary base pairing play in the functions of nucleic acids?
Given the sequences of a particular gene in fruit flies, fish, mice, and humans, predict the relative similarity of the human sequence to that of each of the other species.

**TEST YOUR UNDERSTANDING**

**LEVEL 1: KNOWLEDGE/COMPREHENSION**

1. Which of the following categories includes all others in the list?
   a. monosaccharide
   b. polysaccharide
   c. carbohydrate
   d. carbohydrate

2. The enzyme amylase can break glycosidic linkages between glucose monomers only if the monomers are in the α form. Which of the following could amylase break down?
   a. glycogen, starch, and amylopectin
   b. glycogen and cellulose
   c. cellulose and chitin
   d. starch, chitin, and cellulose

3. Which of the following is true of unsaturated fats?
   a. They are more common in animals than in plants.
   b. They have double bonds in the carbon chains of their fatty acids.
   c. They generally solidify at room temperature.
   d. They contain more hydrogen than do saturated fats having the same number of carbon atoms.

4. The structural level of a protein least affected by a disruption in hydrogen bonding is the
   a. primary level.
   b. secondary level.
   c. tertiary level.
   d. quaternary level.

5. Enzymes that break down DNA catalyze the hydrolysis of the covalent bonds that join nucleotides together. What would happen to DNA molecules treated with these enzymes?
   a. The two strands of the double helix would separate.
   b. The phosphodiester linkages of the polynucleotide backbone would be broken.
   c. The pyrimidines would be separated from the deoxyribose sugars.
   d. All bases would be separated from the deoxyribose sugars.

**LEVEL 2: APPLICATION/ANALYSIS**

6. The molecular formula for glucose is $C_6H_{12}O_6$. What would be the molecular formula for a polymer made by linking ten glucose molecules together by dehydration reactions?
   a. $C_{60}H_{120}O_{60}$
   b. $C_{60}H_{120}O_{61}$
   c. $C_{60}H_{120}O_{50}$
   d. $C_{60}H_{111}O_{51}$

7. Which of the following pairs of base sequences could form a short stretch of a normal double helix of DNA?
   a. 5′-AGCT-3′ with 3′-TCGA-5′
   b. 5′-GGCG-3′ with 3′-TTTA-5′
   c. 5′-ATGC-3′ with 3′-GCAT-5′
   d. All of these pairs are correct.

8. Construct a table that organizes the following terms, and label the columns and rows.
   - Monosaccharides
   - Polypeptides
   - Phosphodiester linkages
   - Fatty acids
   - Triacylglycerols
   - Peptide bonds
   - Amino acids
   - Polynucleotides
   - Glycosidic linkages
   - Nucleotides
   - Polysaccharides
   - Ester linkages

9. **DRAW IT** Copy the polynucleotide strand in Figure 5.24a and label the bases G, T, C, and T, starting from the 5′ end. Assuming this is a DNA polynucleotide, now draw the complementary strand, using the same symbols for phosphates (circles), sugars (pentagons), and bases. Label the bases. Draw arrows showing the 5′ → 3′ direction of each strand. Use the arrows to make sure the second strand is antiparallel to the first. **Hint:** After you draw the first strand vertically, turn the paper upside down; it is easier to draw the second strand from the 5′ toward the 3′ direction as you go from top to bottom.

**LEVEL 3: SYNTHESIS/EVALUATION**

10. **EVOLUTION CONNECTION**
    Comparisons of amino acid sequences can shed light on the evolutionary divergence of related species. If you were comparing two living species, would you expect all proteins to show the same degree of divergence? Why or why not?

11. **SCIENTIFIC INQUIRY**
    Suppose you are a research assistant in a lab studying DNA-binding proteins. You have been given the amino acid sequences of all the proteins encoded by the genome of a certain species and have been asked to find candidate proteins that could bind DNA. What type of amino acids would you expect to see in the DNA-binding regions of such proteins? Why?

12. **WRITE ABOUT A THEME: ORGANIZATION**
    Proteins, which have diverse functions in a cell, are all polymers of the same kinds of monomers—amino acids. Write a short essay (100–150 words) that discusses how the structure of amino acids allows this one type of polymer to perform so many functions.

13. **SYNTHESIZE YOUR KNOWLEDGE**
    Given that the function of egg yolk is to nourish and support the developing chick, explain why egg yolks are so high in fat, protein, and cholesterol.

*For selected answers, see Appendix A.*