STUDY GUIDE

MARTHA R. TAYLOR

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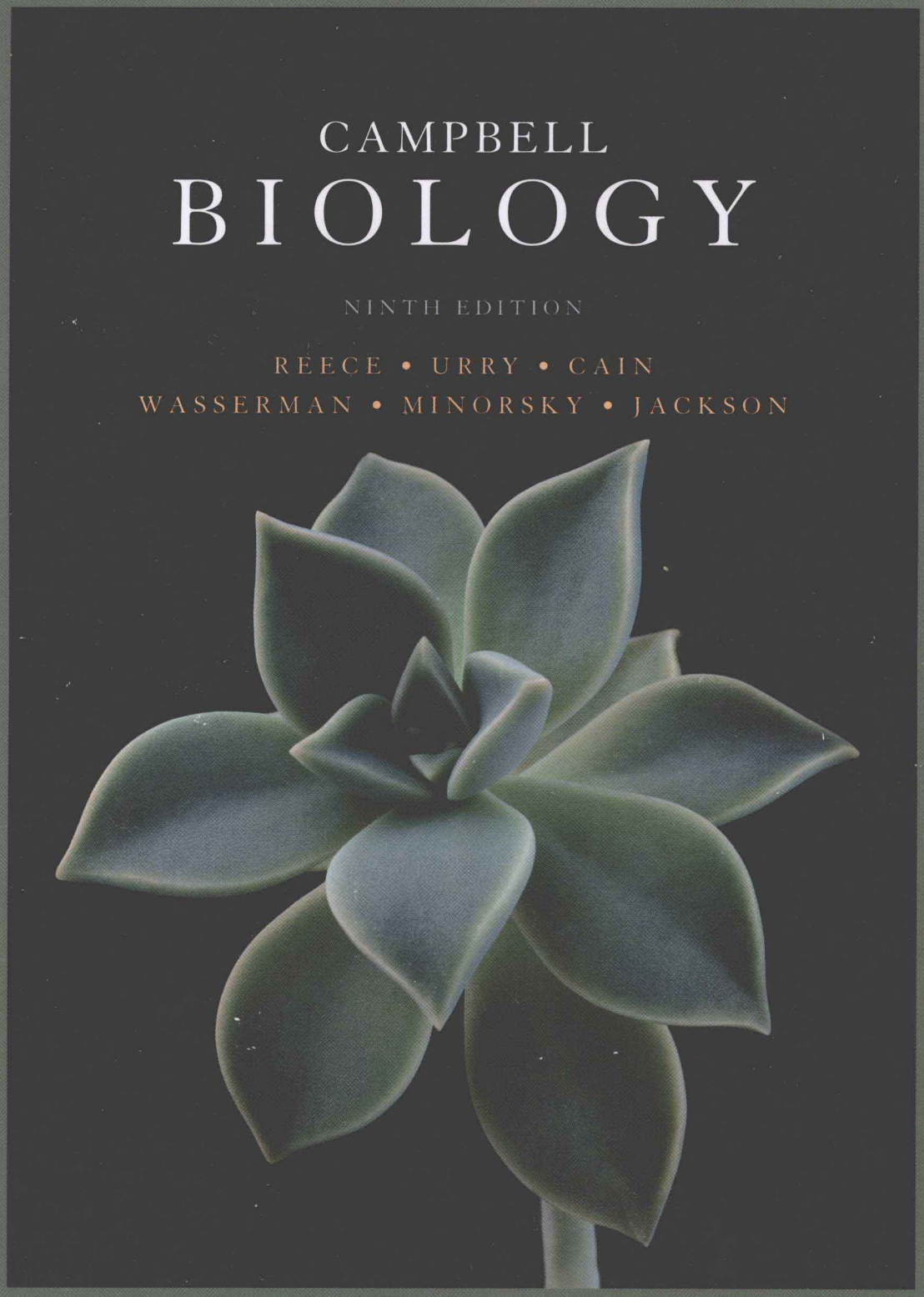

STUDY GUIDE
FOR
CAMPBELL BIOLOGY

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Dedication

To my dad, Kenneth E. Taylor, who still shares his love of learning with me.

Credits

Figures IQ 3.1, IQ 5.3, IQ 5.8, IQ 6.4, SYK 6.3, IQ 7.1, IQ 7.5, SYK 7.2, IQ 8.5, IQ 8.6, IQ 9.5, IQ 9.7, IQ 9.8, IQ 10.1, IQ 10.2, IQ 10.5, IQ 10.8, IQ 12.3, IQ 13.3, IQ 16.2, IQ 16.5, IQ 17.6, IQ 18.4, IQ 19.1, IQ 20.3, SYK 25.2, IQ 26.1, SYK 26.2, IQ 28.3, SYK 28.1, IQ 29.5, SYK 29.2, IQ 30.5, SYK 30.3, IQ 31.4, IQ 33.5, SYK 33.1, IQ 34.1, IQ 34.3, IQ 34.8, IQ 35.1, IQ 35.4, IQ 35.5, SYK 35.2, IQ 36.3, IQ 36.6, IQ 37.5, IQ 38.1, IQ 38.4, IQ 40.2, IQ 40.3, IQ 40.4, SYK 41.1, IQ 42.3, SYK 42.1, IQ 43.5, IQ 44.5, IQ 45.1, IQ 46.3, IQ 46.5, IQ 47.2, IQ 47.3, IQ 47.4, IQ 47.6, IQ 48.1, IQ 48.3, IQ 48.4, IQ 49.3, IQ 50.3, IQ 50.5, IQ 50.8, IQ 52.2, IQ 52.4, IQ 53.2, IQ 53.4, IQ 54.9 : Adapted from Reece, J. B., et al., *Campbell Biology*, 9th ed. (San Francisco, CA: Benjamin Cummings, 2011) © 2011 Pearson Education Inc., publishing as Benjamin Cummings.

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Preface

Another name for the *Student Study Guide* for *Campbell Biology*, Ninth Edition, could be "A Student Structuring Guide." This guide is designed to help you structure and organize your developing knowledge of biology and create your own personal understanding of the topics covered in the text. Take a few minutes to learn about some strategies of successful students, as well as some strategies for using this study guide.

Strategies of Successful Students

What does it take to be a successful student? How can you learn more efficiently and earn better grades? And how can you enjoy your biology course more?

Every successful student tackles learning in his or her own unique way. But there are commonalities that can be shared and results from educational research that can inform you as you develop your own approach. Here is a short list of suggestions that may help.

Make it interesting. Biology is fascinating and so much easier to learn when you love it. Try to bring a sense of wonder to your classes and your studying. Appreciate how much has been discovered and how much we have yet to learn about the living world.

Focus in lecture. What does it mean to focus? Obviously sleeping or texting are out. But so is taking down every word your professor says without thinking. If a lecture outline is provided, take notes on it. Or try taking notes on one page of a notebook and then on the facing page rework, elaborate, or at least make legible what you wrote down in class. Doing this shortly after class helps you review the material while it is fresh and develop an organized set of notes to use in studying for exams.

Make reading active. Research has shown that simply rereading material does not improve test scores, but interacting with the reading assignment does. How do you interact with the printed word? Ask yourself questions and look for answers. Reword every concept heading as a question before you start reading. Make questions out of subheadings. If you are trying to answer a question, you are looking for meaning. Your brain is not just decoding words, it is working toward understanding those words.

Use your resources. What does your course provide—review sessions, office hours, tutors, study groups? Science is a social endeavor; interact with people as well as the material. Use the resources provided by your course and by your textbook: Web sites, practice exams, tutorials. When possible, prepare for exams by practicing with questions from previous exams. Each professor has his/her own approach to writing questions. One way to improve your grade is to study how your professor asks questions.

Learn from your mistakes. Carefully review your exams—the questions you missed and even those you got right. If possible, go over the exam with an instructor. Review both *what* you missed and *why* you missed it, so you can learn *how* to choose the correct answer on the next exam. Work to improve your test-taking skills. (See the section on tips for taking tests.)

Try something new. If what you are doing isn't working, don't just keep trying to do it harder. Experiment with new strategies. Are you a visual learner? Try drawing diagrams. If you are an auditory learner, listen to lecture or study tapes as you commute or exercise. Do you need to interact physically with ideas? Build models and be active in your learning.

Strategies for Using This Study Guide

This study guide is not a replacement for your textbook or biology class. However, it should help support and even streamline your learning process. Some students read the text chapters before lecture and then read the study guide chapters after class to reinforce and review. Others reverse that order, skimming the study guide before lecture and then carefully dissecting the text after the professor's presentation. Use this study

guide to prepare for tests. With the textbook open so you can refer to essential diagrams, read the relevant study guide chapters for a quick review.

Each study guide chapter has the following seven sections:

- The listing of the **Key Concepts** from the text keeps you focused on the major themes of the chapter.
- The **Framework** identifies the overall picture; it provides a conceptual framework into which the chapter's information fits.
- The **Chapter Review** is a condensation of the textbook chapter, including a brief summary for each concept heading. All the bold terms in the text are also shown in boldface in this section. Interspersed in this review section are **Interactive Questions** that help you stop and actively review the material just covered.
- The **Word Roots** section presents the meanings of key biological prefixes, suffixes, and word roots. Examples of terms from the chapter are then defined. Breaking a complicated term into identifiable components will help you to recognize and learn many new biological terms.
- The **Structure Your Knowledge** section directs you to organize and relate the main concepts of the chapter. It helps you to piece together the key ideas into a bigger picture.
- In the **Test Your Knowledge** section, you are provided with objective questions to test your understanding. The multiple choice questions ask you to choose the best answer. Some answers may be partly correct; almost all choices have been written to test your ability to discriminate among alternatives or to point out common misconceptions.
- Suggested answers to the Interactive Questions, the Structure Your Knowledge section, and the Test Your Knowledge questions are provided in the **Answer Section** at the end of the book.

Using Concept Maps. What are the concept maps that appear throughout this study guide? A **concept map** is a diagram that organizes and relates ideas. The *structure* of a concept map is a hierarchically organized cluster of concepts, enclosed in boxes and connected with labeled lines that explicitly state the relationships among concepts. The *function* of a concept map is to help you structure your understanding of a topic and create meaning. The *value* of a concept map is in the thinking and organizing required to create it.

Developing a concept map requires you to evaluate the relative importance of a group of concepts (Which are most inclusive and important? Which are subordinate to other concepts?), arrange the concepts in meaningful clusters, and draw and label the connections between them.

This book uses concept maps in several ways. A map of a chapter may be presented in the Framework section to show the organization of the key concepts in that chapter. An Interactive Question may provide a skeleton map, with some concepts provided and some empty boxes for you to label. This technique is intended to help you become more familiar with concept maps and to illustrate one possible approach to organizing the concepts of a particular section.

You will also be asked to develop your own concept maps on certain subsets of ideas. In these cases, the Answer Section will present a suggested map. A concept map is an individual picture of your understanding at the time you make the map. As your understanding of an area develops, your map will evolve—sometimes becoming more complex and interrelated, sometimes becoming simplified and more streamlined. Do not look to the Answer Section for the "right" concept map. After you have organized your own thoughts, look at the answer map to make sure you have included the key concepts (although you may have added more), to check that the connections you have made are reasonable, and perhaps to see another way to organize the information.

Tips for Taking Multiple Choice Tests. Interact with each question. Read the stem of the question carefully, underlining or using a highlighter to identify the key concept. Read each answer slowly. Cross out the ones you know are wrong. Circle the key idea that you think identifies the correct answer. Now read the question and the answer you chose together, making sure your choice really does answer what is asked. If you aren't sure about a question, try rereading the question and each choice individually. Don't do all of your thinking in your head. Write in the margins and blank spaces of your test. Draw yourself diagrams and pictures. Write down what you do know, and it may jog your memory. If you still are not sure, mark the question and come back to it later. As you work through related questions, you may find information that helps you figure out that question. And remember, there is no substitute for good preparation, proper rest and nutrition, and a positive attitude.

Biology is a fascinating, broad, and exciting subject. *Campbell Biology,* Ninth Edition, is filled with information organized in a manner that will help you build a conceptual framework of the major themes of biology. This *Student Study Guide* is intended to help you learn and recall information and, most importantly, to encourage and guide you as you develop your own understanding of and appreciation for biology.

Martha R. Taylor
Cornell University

Contents

Chapter 1

Introduction: Themes in the Study of Life

Key Concepts

Framework

This chapter outlines the broad scope of biology, describes themes that unify the study of life, and examines the scientific construction of biological knowledge. A course in biology is neither a vocabulary course nor a classification exercise for the diverse forms of life. Biology is a collection of facts and concepts structured within theories and organizing principles. Recognizing the common themes within biology will help you structure your knowledge of the fascinating and challenging study of life.

Chapter Review

Biology is the scientific study of life, with **evolution,** the process of change that has shaped life from its origin on Earth to today's diversity, as its organizing principle. The properties and processes of life include highly ordered structure, evolutionary adaptation, response to the environment, regulation, energy processing, reproduction, and growth and development.

1.1 The themes of this book make connections across different areas of biology

Theme: New Properties Emerge at Each Level in the Biological Hierarchy The scale of biology extends from the biosphere to molecules.

INTERACTIVE QUESTION 1.1

Write a brief description of each of the following levels of biological organization.

a. biosphere

b. ecosystem

c. community

d. population

e. organism

f. organs and organ systems

g. tissues

h. cells

i. organelles

j. molecules

Interactions among components at each level of biological organization lead to the emergence of novel properties at the next level. These **emergent properties** result from the structural arrangement and interaction of parts.

Biology combines the powerful and pragmatic strategy of reductionism, which breaks down complex systems into simpler components, with the study of the holistic, highly complex interactions in higher levels of life.

Many researchers are seeking to understand the emergent properties of life by looking at the functional integration of a system's parts. **Systems biology** studies the interactions of the parts of a system and models the system's dynamic behavior.

INTERACTIVE QUESTION 1.2

Give examples of how systems biology may affect medical practice or environmental policy making.

Theme: Organisms Interact with Other Organisms and the Physical Environment Both organisms and the environment are affected by interactions between them. These interactions result in the cycling of chemical nutrients between organisms and the environment. The continual burning of fossil fuels, which releases increasing amounts of CO_2 to the atmosphere, is causing global warming and contributing to **global climate change.** The resulting increase in temperature affects organisms' habitats and interactions.

Theme: Life Requires Energy Transfer and Transformation Living organisms require energy. Producers transform light energy to the chemical energy in sugar, which powers the cellular activities of plants. Consumers eat plants and other organisms, using the chemical energy in their foods to power their movement, growth, and other activities. In each energy transformation, some energy is converted to thermal energy, which is dissipated to the surroundings as heat.

INTERACTIVE QUESTION 1.3

Compare the movement of chemical nutrients and energy in an ecosystem.

Theme: Structure and Function Are Correlated at All Levels of Biological Organization The form of a biological structure is usually well matched to its function. Form fits function at all of life's structural levels.

Theme: Cells Are an Organism's Basic Units of Structure and Function The cell is the lowest structural level capable of performing all the activities of life. Every cell uses DNA as its genetic information and is enclosed by a membrane. The simpler and smaller **prokaryotic cell,** unique to bacteria and archaea, lacks both a nucleus to enclose its DNA and cytoplasmic organelles. The **eukaryotic cell**—with a nucleus containing DNA, and numerous membrane-bound organelles—is typical of all other living organisms.

Theme: The Continuity of Life Is Based on Heritable Information in the Form of DNA The heritable information of a cell is coded in **DNA,** deoxyribonucleic acid, the substance of genes. **Genes** are the units of inheritance that transmit information from parents to offspring. Genes are located on chromosomes, long DNA molecules that replicate before cell division and provide identical copies to daughter cells.

The biological instructions for the development and functioning of organisms are coded in the arrangement of the four kinds of nucleotides on the two strands of a DNA double helix. Most genes program the cell's production of proteins, and almost all cellular structures and actions involve one or more proteins.

Gene expression is the process by which a gene's information is converted into a protein or an RNA product. All forms of life use essentially the same genetic code of nucleotides.

INTERACTIVE QUESTION 1.4

Describe the pathway from DNA nucleotides to proteins.

All the genetic instructions an organism inherits make up its **genome.** One set of human chromosomes contains about 3 billion nucleotide pairs, and codes for the production of about 75,000 proteins and a large number of non-protein-coding RNA molecules.

With the sequencing of the human genome and the genomes of many other organisms now complete, current research focuses on the coordination of the proteins coded for by the DNA sequences on a cellular and organismal level. Using a systems approach called **genomics,** scientists are analyzing whole sets of genes of a species and comparing genomes between species.

Three research developments contribute to genomics: "high-throughput" technology that can produce enormous amounts of data, such as the automatic DNA-sequencing machines; **bioinformatics,** which provides the computational tools to process and integrate data

from large data sets; and interdisciplinary research teams with specialists from many diverse scientific fields.

Theme: Feedback Mechanisms Regulate Biological Systems Protein enzymes catalyze a cell's chemical reactions. Many biological systems self-regulate by a mechanism called feedback. In **negative feedback,** an end product slows down a process, often by inhibiting an enzyme early in a chemical pathway. In **positive feedback,** less common in biological processes, an end product speeds up its own production. Regulatory mechanisms operate at all levels of the biological hierarchy.

Evolution, the Overarching Theme of Biology Evolution explains how diverse organisms of the past and the present are related through common ancestry, and it presents the mechanism through which organisms come to fit their environments.

1.2 The Core Theme: Evolution accounts for the unity and diversity of life

Classifying the Diversity of Life Of an estimated total of 10–100 million species, only about 1.8 million species have been identified and named. Taxonomy is the branch of biology that names organisms and groups species into ever broader categories, from genera to family, order, class, phylum, kingdom, and domain.

The number of kingdoms is an ongoing debate, but all of life is now grouped into three domains. The prokaryotes are divided into domains **Archaea** and **Bacteria.** All eukaryotes are placed in domain **Eukarya.** Within the Eukarya, the traditional kingdom Protista is being split to better reflect evolutionary relationships.

Within this diversity, living forms share a universal genetic language of DNA and similarities in cell structure.

INTERACTIVE QUESTION 1.5

What is a commonly used criterion for placing plants, fungi, and animals into separate kingdoms?

Charles Darwin and the Theory of Natural Selection In *The Origin of Species*, published in 1859, Charles Darwin presented his case for "descent with modification," the idea that present forms have diverged from a succession of ancestral forms. Darwin proposed the theory of **natural selection** as the mechanism of evolution by drawing an inference from three observations: Individuals vary in many heritable traits, the overproduction of offspring sets up a competition for survival, and species are generally matched to their environments. From this, Darwin inferred that individuals with traits best suited for an environment leave more offspring than do less-fit individuals. This natural selection, or unequal reproductive success within a population, results in the gradual accumulation of favorable adaptations to an environment.

The Tree of Life The underlying unity seen in the structures of related species, both living and in the fossil record, reflects the inheritance of that structure from a common ancestor. The diversity of species results from natural selection acting over millions of generations in different environments. The tree-like diagrams of evolutionary relationships reflect the branching genealogy extending from ancestral species. Similar species share a common ancestor at a more recent branch point on the tree of life. Distantly related species share a more ancient common ancestor.

INTERACTIVE QUESTION 1.6

Describe in your own words Darwin's theory of natural selection as the mechanism of evolutionary adaptation and the origin of new species.

1.3 In studying nature, scientists make observations, and then form and test hypotheses

Science is an approach to understanding the natural world that involves **inquiry,** the search for information by asking questions and endeavoring to answer them.

Making Observations Careful and verifiable observation and analysis of data are the basis of scientific inquiry. Observations involve our senses and tools that extend our senses; **data,** both *quantitative* and *qualitative*, are recorded observations. Using **inductive reasoning,** a generalized conclusion can often be drawn from collections of observations.

Forming and Testing Hypotheses Observations and inductions lead to the search for natural causes and explanations. A **hypothesis** is a tentative answer to a question or an explanation of observations, and it leads to predictions that can be tested. **Deductive reasoning** uses "if . . . then" logic to proceed from the general to the specific—from a general hypothesis to specific predictions of results if the general premise is correct.

A hypothesis must be *testable* and *falsifiable*—that is, there must be some observation or experiment that can reveal if the hypothesis is actually not true. The ideal is to frame two or more alternative hypotheses and design experiments to test each candidate explanation. A hypothesis cannot be *proven*; the more attempts to falsify it that fail, however, the more a hypothesis gains credibility.

Science seeks natural causes for natural phenomena; it does not address questions of the supernatural.

The Flexibility of the Scientific Method The *scientific method*, as outlined by a structured series of steps, is rarely adhered to rigidly in scientific inquiry. Scientists often backtrack to make more observations, or make progress in answering a question only after other research provides a new context.

A Case Study in Scientific Inquiry: Investigating Mimicry in Snake Populations The scarlet king snake mimics the ringed coloration of the venomous coral snake. D. and K. Pfennig and W. Harcombe tested the hypothesis that mimicry is an adaptation that reduces a harmless animal's risk of being eaten. To test the prediction that predators will attack king snakes less frequently in areas where predators have adapted to the warning coloration of coral snakes, they placed equal numbers of plain brown and ringed-colored artificial king snakes in regions with and without coral snakes. Compared to the brown snakes, the ringed snakes were attacked less frequently only in field sites within the range of the venomous coral snakes.

This experimental design illustrates a **controlled experiment** in which subjects are divided into an *experimental group* and a *control group*. Both groups are alike except for the one variable that the experiment is trying to test. Another characteristic of science is that observations and experimental results must be repeatable.

INTERACTIVE QUESTION 1.7

a. How did predators "learn" to avoid coral snakes?

b. Why were the results of the mimicry study presented as the percent of attacks on king snakes in each area rather than as the total number of attacks?

Theories in Science A **theory** is broader in scope than a hypothesis, generates many specific hypotheses, and is supported by a large body of evidence. Still, a theory can be modified or even rejected when results and new evidence no longer support it.

1.4 Science benefits from a cooperative approach and diverse viewpoints

Building on the Work of Others Most scientists work in teams and share their results with a broader research community in seminars, publications, and websites. Scientists often attempt to confirm the observations and experimental results of other colleagues. Scientists often share data on **model organisms,** which are easy to grow in the lab and are useful for answering particular questions that may have broad applications. Biological questions can be approached from different angles and levels of biological organization.

Science, Technology, and Society The political and cultural environment influences the ways in which scientists approach their work. But science is still distinguished by adherence to the criteria of verifiable observations and hypotheses that are testable and falsifiable.

Science and technology are interdependent: The information generated by science is applied by **technology** in the development of goods and services, and technological advances are used to extend scientific knowledge. The uses of scientific knowledge and technologies are influenced by and in turn influence politics, economics, and cultural values.

The Value of Diverse Viewpoints in Science Women and many racial and ethnic groups have been underrepresented in scientific professions. A diversity of backgrounds and viewpoints is important to the progress of science.

INTERACTIVE QUESTION 1.8

a. Compare hypotheses and theories.

b. Compare science and technology.

Word Roots

bio- = life (*biology:* the scientific study of life; *bioinformatics:* the use of computers, software, and mathematical models to process and integrate biological information from large data sets)

-ell = small (*organelle:* a small membrane-enclosed structure with a specialized function, found in eukaryotic cells)

eu- = true (*eukaryotic cell:* a type of cell with a membrane-enclosed nucleus and organelles)
pro- = before; **karyo-** = nucleus (*prokaryotic cell:* a type of cell lacking a membrane-enclosed nucleus and organelles)

Structure Your Knowledge

1. Briefly describe in your own words each of the eight unifying themes of biology presented in this chapter:
   a. emergent properties
   b. interaction with the biotic and physical environment
   c. energy transfer and transformation
   d. structure and function
   e. cells
   f. heritable information
   g. feedback mechanisms of regulation
   h. evolution

Test Your Knowledge

MULTIPLE CHOICE: *Choose the one best answer.*

1. The core idea that makes sense of the unity and the diversity of life is
   a. the scientific method.
   b. inductive reasoning.
   c. deductive reasoning.
   d. evolution.
   e. systems biology.

2. In an experiment similar to the mimicry experiment performed by the Pfennigs, a researcher found that more total predator attacks occurred on model king snakes in areas with coral snakes than in areas outside the range of coral snakes. From this the researcher concluded that
   a. the mimicry hypothesis is false.
   b. the predators in the areas with coral snakes were hungrier than the predators in other areas.
   c. king snakes do not resemble coral snakes enough to protect them from attack.
   d. the data that should be compared to draw a conclusion must include a control—a comparison with the number of attacks on model brown snakes.
   e. more data must be collected before a conclusion can be drawn.

3. Why can a hypothesis never be "proven" to be true?
   a. One can never collect enough data to be 100% sure.
   b. There may always be alternative untested hypotheses that might account for the results.
   c. Science is limited by our senses.
   d. Experimental error is involved in every research project.
   e. Science "evolves"; hypotheses and even theories are always changing.

4. Which of the following statements is an example of positive feedback regulation?
   a. The hormones insulin and glucagon regulate blood-sugar levels.
   b. In the birth of a baby, uterine contractions stimulate release of chemicals that stimulate more uterine contractions.
   c. A rise in temperature when you exercise stimulates sweating and increased blood flow to the skin.
   d. When cells have sufficient energy available, the pathways that break down sugars are turned off.
   e. A rise in CO_2 in the atmosphere correlates with increasing global temperature.

5. Which of the following areas is mismatched with its description?
   a. model organisms—using type organisms to characterize each domain and kingdom
   b. scientific inquiry—generating hypotheses; formulating predictions; conducting experiments or making observations
   c. genomics—studying whole sets of genes of a species and between species
   d. taxonomy—identifying and naming organisms, and placing them in hierarchical categories
   e. technology—inventing practical uses of scientific knowledge

6. In a pond sample, you find a unicellular organism that has numerous chloroplasts and a whiplike flagellum. In which of the following groups do you think it should be classified?
   a. plant
   b. animal
   c. domain Archaea
   d. one of the proposed kingdoms of protists
   e. You cannot tell unless you see if it has a nucleus.

7. What is DNA?
   a. the substance of heredity
   b. a double helix made of four types of nucleotides
   c. a code for protein synthesis
   d. a component of chromosomes
   e. all of the above

8. Which of the following sequences correctly lists life's hierarchical levels from lowest to highest?
   a. organ, tissue, organ system, organism, population
   b. organism, community, population, ecosystem, biosphere
   c. molecule, organelle, cell, tissue, organ, organism
   d. tissue, cell, organ, organism, community
   e. Both b and c are correct sequences.

9. Which of the following themes of biology is most related to the goals and practices of systems biology?
   a. Evolution accounts for the unity and diversity of life.
   b. Cells are an organism's basic units of structure and function.
   c. The continuity of life is based on heritable information in the form of DNA.
   d. Life requires energy transfer and transformation.
   e. New properties emerge at each level in the biological hierarchy.

UNIT 1

The Chemistry of Life

Chapter 2

The Chemical Context of Life

Key Concepts

2.1 Matter consists of chemical elements in pure form and in combinations called compounds

2.2 An element's properties depend on the structure of its atoms

2.3 The formation and function of molecules depend on chemical bonding between atoms

2.4 Chemical reactions make and break chemical bonds

Framework

This chapter considers the basic principles of chemistry that explain the behavior of atoms and molecules. You will learn how the subatomic particles—protons, neutrons, and electrons—are organized in atoms, how atoms are connected by covalent bonds, and how ions are attracted to each other in ionic bonds. Weak chemical bonds help to create the shapes and functions of molecules. Emergent properties are associated with each new level of structural organization in the hierarchy from atoms to life.

Chapter Review

2.1 Matter consists of chemical elements in pure form and in combinations called compounds

Elements and Compounds **Matter** is anything that takes up space and has mass. (Although sometimes used interchangeably, mass is the amount of matter in an object, whereas weight reflects gravity's pull on that mass.) **Elements** are substances that cannot be chemically broken down to other types of matter. A **compound** is made up of two or more elements combined in a fixed ratio. The characteristics of a compound differ from those of its constituent elements, an example of emergent properties in higher levels of organization.

The Elements of Life Carbon (C), oxygen (O), hydrogen (H), and nitrogen (N) make up 96% of living matter. The seven elements listed in Interactive Question 2.1 make up most of the remaining 4%. Some elements, like iron (Fe) and iodine (I), may be required in very minute quantities and are called **trace elements.**

INTERACTIVE QUESTION 2.1

Fill in the names beside the symbols of the following elements commonly found in living matter.

Ca	Na
P	Cl
K	Mg
S	

Evolution of Tolerance to Toxic Elements Serpentine soil contains toxic elements and low levels of essential elements. Serpentine plant communities exhibit evolutionary adaptations that allow such plants to grow in toxic soils.

2.2 An element's properties depend on the structure of its atoms

An **atom** is the smallest unit of matter retaining the properties of a particular element.

Subatomic Particles Three stable *subatomic particles* are important to our understanding of atoms. Uncharged **neutrons** and positively charged **protons** are packed tightly together to form the **atomic nucleus** of an atom. Negatively charged **electrons** form a cloud around the nucleus.

Protons and neutrons have a similar mass of about 1.7×10^{-24} g, or close to 1 dalton each. A **dalton** is the measurement unit for atomic mass. Electrons have negligible mass.

Atomic Number and Atomic Mass Each element has a characteristic **atomic number,** or number of protons in the nucleus of each of its atoms. Unless otherwise indicated, an atom has a neutral electrical charge, and thus the number of protons is equal to the number of electrons. A subscript to the left of the symbol for an element indicates its atomic number; a superscript indicates its mass number. The **mass number** is equal to the number of protons and neutrons in the nucleus and approximates the mass of an atom of that element in daltons. The term **atomic mass** refers to the total mass of an atom.

INTERACTIVE QUESTION 2.2

The difference between the mass number and the atomic number of an atom is equal to the number of _____. An atom of phosphorus, $^{31}_{15}P$, contains _____ protons, _____ electrons, and _____ neutrons. The atomic mass of phosphorus is approximately _____.

Isotopes Although the number of protons is constant, the number of neutrons can vary among the atoms of an element, creating different **isotopes** that have slightly different masses but the same chemical behavior. Some isotopes are unstable; the nuclei of **radioactive isotopes** spontaneously decay, giving off particles and energy. Radioactive isotopes are important tools in biological research and medicine. Too great an exposure to radiation from decaying isotopes poses a significant health hazard.

The Energy Levels of Electrons **Energy** is defined as the capacity to cause change. **Potential energy** is energy stored in matter as a consequence of its position or structure. The potential energy of electrons increases as their distance from the positively charged nucleus increases. Electrons can be located in different **electron shells** surrounding the nucleus.

INTERACTIVE QUESTION 2.3

To move to a shell farther from the nucleus, an electron must _____ energy; an electron _____ energy when it moves to a closer shell.

Electron Distribution and Chemical Properties The chemical behavior of an atom is a function of the distribution of its electrons—in particular, the number of **valence electrons** in its outermost electron shell, or **valence shell.** A valence shell of eight electrons is complete, resulting in an unreactive or inert atom. (The first shell, however, can hold only two electrons.) Atoms with incomplete valence shells are chemically reactive. The elements in each row, or period, of the *periodic table of the elements* have the same number of electron shells and are arranged in order of increasing number of electrons.

INTERACTIVE QUESTION 2.4

Draw an electron shell diagram for the following atoms.

a. $_{6}C$ **c.** $_{8}O$

b. $_{7}N$ **d.** $_{12}Mg$

Electron Orbitals An **orbital** is the three-dimensional space or volume within which an electron is most likely to be found. No more than two electrons can occupy the same orbital. The first electron shell can contain