Study Guide

to accompany

PURVES
ORIANS
HELLER

FOURTH EDITION

LIFE
The Science of Biology

Jon C. Glase
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Study Guide

to accompany

Purves, Orians, and Heller

LIFE: The Science of Biology

Fourth Edition

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W. H. Freeman and Company

THE COVER

Elephants at a water hole in northern Botswana, Africa.
Photograph by Frans Lanting/Minden Pictures.

Study Guide to accompany
LIFE: THE SCIENCE OF BIOLOGY, Fourth Edition

Address editorial correspondence to
Sinauer Associates, Inc.
23 Plumtree Road
Sunderland, Massachusetts 01375 U.S.A.

Address orders to W. H. Freeman and Co.
Distribution Center, 4419 West 1980 South,
Salt Lake City, Utah 84104 U.S.A.

ISBN 0–7167–2655–6

Printed in U.S.A.

4 3

STUDY GUIDE

to accompany

LIFE: The Science of Biology

Fourth Edition

PREFACE

THE PURPOSE OF THIS STUDY GUIDE

A well-written, current textbook is an essential element in the serious study of any complex subject such as biology. Our collective experience in teaching biology during the past 20 years suggests that many students can use their textbooks more effectively if a well-conceived study guide is available to them. Our motivation in writing this guide is to help you learn about biology using the fourth edition of the textbook *Life: The Science of Biology* (1995) by Purves, Orians, and Heller.

To be effective, the study guide that accompanies a biology textbook should facilitate your learning process in two fundamental ways. First, it should help you *clarify* the important concepts and principles in each of the areas of biology. The textbook is designed to explain concepts and principles using a combination of descriptive text, illustrative artwork, and useful examples. Unfortunately, students sometimes lose sight of the major ideas and themes in biology because they fail to distinguish between the essential information and the supportive details. A major goal of our guide is to "unpack" the large quantity of information presented in the textbook, and to restate the most important ideas as a list of *Key Concepts* within each chapter. In writing these concept statements we have attempted to be concise and include only the essence of the idea being considered in the textbook. Sometimes a key concept item will include several closely related concepts which should be learned together. Bear in mind that this study guide is meant to be a *companion* to the textbook; the study guide's key concepts will only be meaningful after you have carefully studied how these ideas are developed in the corresponding chapter of the textbook.

A second major goal of our guide is to provide you with *feedback* about your level of understanding of the key concepts. For each chapter of the textbook, we have developed activities and questions that will test your mastery of the material covered. Some questions test your knowledge of terminology, others examine the relationships between key concepts, and some questions require you to think about biological concepts in a novel way, or perhaps use those concepts to solve a problem. The answers to all questions are presented in the *Answers and Explanations* sections of the guide, with each answer carefully explained and indexed to the key concept(s) related to that question. If you do not understand a question in the study guide, or our proposed answer and its explanation, then you may need to return to the textbook for further review.

HOW TO USE THIS STUDY GUIDE

We suggest that the best approach you can take to the study of biology is a structured approach. Treat the textbook as your primary information source and study it first. Scanning through assigned textbook pages will help to prepare you for lectures, laboratories, or discussion sections covering a specific topic. However, do not expect to completely comprehend all of the ideas you encounter during your first reading of the textbook. Rather, begin by scanning the chapter to understand how it is organized, see what the main topics are, and identify major themes. At the same time, read the corresponding portions of the study guide to further help you identify key concepts as they are presented in the textbook.

After you have attended the lecture, lab, or discussion, you will be in a much better position to clearly identify the material your instructor considers most important. To assist you in this process, we have included a set of *Learning Objectives* at the beginning of each chapter in the study guide. Your instructor may select a subset of objectives from this list, or even add to it. Careful study of the subject on your part should provide you with the necessary understanding to give a complete answer to each of these objectives. Check off each objective as you master it.

After identifying the relevant learning objectives for a specific topic, you should return to the textbook chapter and read the assignment in detail. During this in-depth study session, try to relate information in the textbook to the ideas presented in the study guide, your lecture notes, or laboratory exercises. We have divided each chapter of the study guide into several sections, each of which includes about as much textbook information as you are likely to assimilate during a short, productive study session before taking a short break.

Active involvement will promote your learning, so you should have paper available to write down important terms and to highlight sections of the textbook or study guide. Thoughtfully study the tables and figures included in each chapter. The artwork in your textbook has been carefully designed to help convey information that is difficult to explain using text alone; this includes conceptual relationships as well as the dynamic interactions that take place between the components of biological systems. Sometimes a single diagram can tie together and give meaning to several paragraphs of description. At all times, try to relate new information to what you already know. Use the index of your textbook wisely to locate previously covered information that may need to be reviewed as you take on new material. Remember that the study of biology is a cumulative process, and review is constantly needed as you progress to more complex, abstract material.

After you have actively studied part or all of a chapter in the textbook and the relevant sections of the study guide, you are ready to test your understanding by answering the accompanying study guide questions. We have provided space in the study guide so that you can write your responses to questions directly in the book, circle your answers to multiple choice questions, and make any sketches or calculations required in the various activities. If you encounter difficulty with a question, do not be tempted to short-circuit the learning process by looking at the *Answers and Explanations* section. Instead, you should review that section's key concepts and consult the textbook until you can make a reasonable choice from the possible answers given. Sometimes several choices will seem partially correct. In this case pick the *best*, most specific answer available. When you do make a choice, you should also be able to explain *why* the other choices are incorrect in terms of the key concepts presented in the study guide.

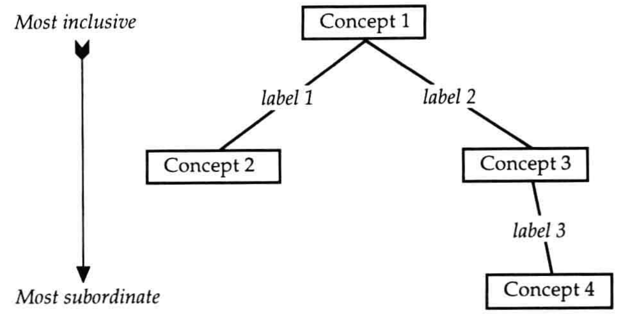
Since your mind works best in short, focused learning sessions, take a break after you have completed one section of the study guide. When you return to your study of biology, it is a good idea to quickly review the most recently studied section before proceeding to new material.

ADDITIONAL AIDS TO STUDYING BIOLOGY

Concept Mapping

It has been estimated that the number of new words encountered in a typical introductory biology course surpasses the vocabulary introduced during the first year of a foreign language course. Rote learning is a very inefficient approach for mastering this terminology, because the act of simply memorizing a new term without connecting it to the things you already know about the topic only promotes short-term learning. To take the analogy further, one does not learn a foreign language simply by memorizing the dictionary. The language can only be learned by understanding the concepts of grammar and syntax that allow you to manipulate the vocabulary in a meaningful fashion. Meaningful, long-term learning therefore occurs when you link new information to the knowledge you already possess. If you attempt to learn a concept meaningfully, then the concept will likely be remembered for a much longer time, and in a more readily accessible form. Educational psychologists have proposed several methods for promoting meaningful learning—one such method is called *concept mapping*.

A concept map is a diagram that shows the relationships between concepts within a topic, making it easier to relate new information to what you already know. As shown in the following generic example, concept maps are usually constructed from top to bottom. Each concept is placed in a box, with the most inclusive concepts near the top, and the more subordinate concepts nearer the bottom. The concept boxes are then connected by labeled lines that indicate the relationship between linked concepts.



When constructing a concept map, it is best to select a fairly well-defined topic on which to focus. For example, the map at the top of the next page depicts information included under the heading *Characteristics of Living Organisms* found on pages 1–3 of the textbook, and described in key concepts 1–9 on pages 1–2 of the study guide. Notice that the concept map is simply a compact representation of the information found in the two book sources.

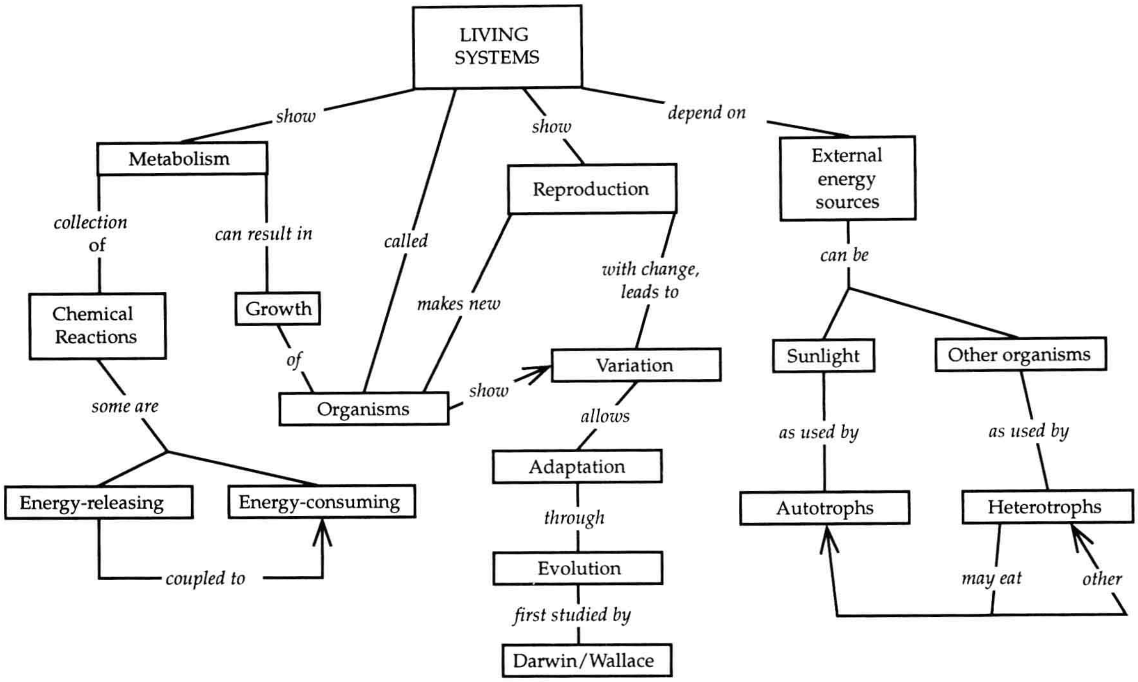
The real educational value of concept mapping comes from the actual construction of the map; you have to do it yourself! As you select concepts to include, you must define the relationships between these concepts and look for links to other concepts already present in the map. This makes the information meaningful for you. To make a map, select a group of key concepts that seem to be logically related. Terms in italics in the study guide are good candidates for inclusion as concepts in your map. Connect the concepts together with labels that make the relationships between concepts explicit. Since this is a dynamic learning process, it is best to do your map construction in pencil and to have an eraser handy—a map tends to change and evolve as your knowledge of the topic grows.

Taking Notes

Note taking is best viewed as yet another means of active learning. While this learning tool will most likely be applied to a lecture, laboratory, or discussion setting, it can also help in your efforts to understand the textbook and study guide materials. Like concept mapping, an emphasis should be placed on organizing the material in your notes in a way that has particular meaning for you. Your notes therefore should not simply be a written record of what the lecturer or textbook has to say about a topic. Instead, they should be a running account of your attempts to conceptually link the material you learned previously with the new material currently under study.

Although there is no one "right way" to take effective notes, following a few simple guidelines will increase the utility of your notes as a learning tool.

1. *Identify major themes* in the topic you are studying and use those themes as the section headings within your notes. In the case of lectures, this strategy will be greatly enhanced if you have already previewed the material being covered before coming to class.
2. *Record the key concepts* mentioned by the lecturer, but be sure to spend most of your time concentrating on what



is being said about those concepts. One of the most important roles of a textbook is to provide the details that support the concepts presented in a lecture or laboratory setting. You should therefore rely on the book to provide much of the detail, rather than spending all of your time during lecture trying to write down things that are already available in your books and running the risk of missing most of what is being said. Think of the lecture as another way to prepare for the detailed reading of the textbook.

3. *Leave space in your notes* to include questions for the lecturer about the material just covered, to insert comments regarding relevant illustrations, and to fill in important or clarifying details as you read about the topic in the textbook. You should also strive to relate material from one section of a lecture to material in other sections, or to material presented in earlier lectures. If you get in the habit of asking "how" and "why" questions about the material you are currently studying, this will help you understand the connections between concepts and principles throughout the entire course.
4. *Develop a shorthand code* for common terms and phrases to increase your note-taking speed. Remember that your notes need not make sense to anyone but you, so feel free to use whatever abbreviations make sense in order to minimize the time spent writing while maximizing the time you devote to listening.

Preparing for and Taking Examinations

Unfortunately, examinations are a fact of life in the classroom. They come in many forms, ranging from oral examinations to essay and multiple choice formats. Although potentially stressful, examinations can also provide an excellent means of assessing your understanding of biology.

There is no better way to prepare for an exam than to practice answering exam questions. Your instructor may provide old examinations with which to practice, but even if this is not the case, you can still gain practice by creating your own exam questions. The idea here is not to "outguess" the instructor, but rather to try and make connections between linked concepts by organizing ideas in a logical, related fashion.

Studying for an exam should be an ongoing process which begins immediately after the previous exam. Do not expect to master a complex subject such as biology by cramming for many hours just prior to a test. Careful study spread over a period of many days or weeks prior to the exam not only makes the task more manageable, but also fosters long-term understanding of concepts.

If your test will have essay questions, practice writing the essays as part of your studying. The mechanics of organizing an answer in your head and actually writing it down on paper will help promote conceptual understanding. During the exam, make a brief outline of your essay before writing the answer; this will help insure that you cover all aspects of the topic.

Many biology examinations, especially those given in large lecture classes, are of necessity done using a multiple choice format. Students are often frustrated by these examinations because they fail to apply their understanding of a topic when answering the question. Assuming that you have spent the time needed to master the conceptual basis of a topic, the following strategy will greatly improve your chances of successfully answering multiple choice questions:

1. *Read the question carefully.* It is impossible to answer a question correctly if you don't understand what's being asked, so take the time to thoroughly read the premise

statement of the question. For example, are you to choose the true or false statement, the exception or the generalization? If necessary, underline key words that help you focus on the main point of the question.

2. *Answer the question in your own way before looking at the answers.* After you understand the question, cover up the possible answers and attempt to think of all relevant concepts and examples related to that question. This puts the question in terms that you already understand, which makes it easier for you to evaluate the possible answers offered by your instructor.
3. *Systematically evaluate each possible answer.* Uncover the answers and carefully evaluate each possibility based on what you have just reviewed about the topic. Assuming that you really do understand the material, you will likely be surprised at how many of the items you thought of will be present in the possible answers.
4. *Don't overthink the solution.* If you have followed steps 1–3 above, then you should be able to identify one best answer without much effort. As long as you have carefully read the question and truly understand the material, more often than not, second-guessing will produce the wrong answer. If you do decide to change your answer, ask yourself why the alternative choice is a better one.

Post-Exam Review

You can often learn a great deal about biology, about your study habits, and about how to successfully take a test, from a thorough review of your exam. Go back and reconsider the questions you got wrong, trying to understand where your thinking went astray. Did you read the question carefully? Did you consider all possible answers? Did you simply spend too little time thinking carefully about each answer? Did you have an inaccurate understanding of the material? Were your notes accurate? Make it a point to return to the textbook or study guide and correct any faulty understanding you brought into the exam, since biology courses frequently build upon material presented during earlier portions of the course.

Seeking Help

The field of biology is vast. There will be an ever-growing body of information that builds as you progress through your biology course, and a time may come when you need assistance to clarify your understanding beyond that provided by this study guide. Realize that there is no dishonor in not understanding everything you read in a textbook or hear in lecture, and do not let yourself become overwhelmed or intimidated. If you are having trouble, please seek help from your instructor, tutors, fellow students, or other available resources.

ACKNOWLEDGEMENTS

We wish to acknowledge the assistance of several colleagues and the forbearance of our families and friends during the preparation of this study guide. Ideas for several of the questions included in this book came from examinations prepared for the introductory biology courses at Cornell University and Clemson University by Kraig Adler, Carl Hopkins, Antonie Blackler, and William Surver. We also thank the authors of *Life: The Science of Biology* for their careful reading of the study guide and for the many suggestions they provided during its development. Any remaining errors, mis-statements, or omissions are our own. Special thanks go out to the staff at Sinauer Associates for assistance during the developmental, editorial, and production phases of this book. We want to especially acknowledge the editorial assistance of Kerry Falvey.

The authors and publisher encourage and appreciate any suggestions that you may have for ways to make this study guide more useful. Good luck in your study of biology, and may you find it as interesting and exciting as we do!

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CONTENTS

1

The Science of Biology

CHAPTER LEARNING OBJECTIVES—after studying this chapter you should be able to:

- ❑ Describe three processes that characterize living things.
- ❑ Differentiate between autotrophs and heterotrophs.
- ❑ Define the term "homeostasis" and explain the importance of homeostasis to metabolism.
- ❑ Explain what is meant when we say that an organism is adapted to its environment and explain how adaptations arise.
- ❑ Describe the features and relationships of the following common levels in the hierarchical organization of biology: molecule, cell, tissue, organ, organism, species, population, community, biome, biosphere.
- ❑ Relate the concept of emergent properties to the hierarchical organization of biology.
- ❑ Describe the four stages of the hypothetico-deductive approach.
- ❑ Describe the relationship between a hypothesis and a null hypothesis and a hypothesis and a theory.
- ❑ Describe the strengths and weaknesses of laboratory and field experimentation.
- ❑ Describe the relationship between surface area and volume as the size of an object increases.
- ❑ Explain how metabolism and exchange of energy and materials with the environment vary with the surface area and volume of an organism.
- ❑ Explain the relationship between the size of supporting appendages and body size.
- ❑ Explain how naturally occurring radioactive materials and the arrangement of rock layers can be used to obtain both absolute and relative ages of evolutionary events.
- ❑ Describe differences in the time scales used to study physiology, population biology, microevolution, and macroevolution.
- ❑ Explain the organizing principles of biology concerned with (1) the laws of chemistry and physics, (2) organisms as energy-capturing/transforming systems, (3) the transmission of genetic information, (4) the cell theory, and (5) the role of natural selection in the evolution of adaptation.
- ❑ Describe some of the arguments advanced by Buffon against the special creation of organisms.
- ❑ Explain the theory of evolutionary change developed by Lamarck.
- ❑ List the underlying ideas that Darwin used to develop his theory of evolution.
- ❑ Explain why variation within a species and the potential for exponential growth shown by many populations are important to Darwin's theory.
- ❑ Describe natural selection and how it differs from artificial selection.
- ❑ Define paradigm and explain the Darwinian paradigm.
- ❑ Describe a hypothesis for the origin of eukaryotic cells from prokaryotic cells.
- ❑ Name and describe the distinguishing features of the six kingdoms of life.

CHARACTERISTICS OF LIVING ORGANISMS • THE HIERARCHICAL ORGANIZATION OF BIOLOGY • THE METHODS OF SCIENCE (pages 1–9)

Key Concepts

1. Living things (organisms) are characterized by three processes: metabolism, regulated growth, and reproduction.
2. All of the energy-consuming and energy-releasing chemical reactions occurring within living systems are called *metabolism*.
3. *Autotrophs* synthesize their own organic molecules using energy from inorganic sources, either sunlight or simple chemicals.
4. *Heterotrophs* obtain energy from complex chemicals produced either directly or indirectly by autotrophs.
5. In response to changes in the external environment, organisms vary the rates of their chemical reactions in order to maintain relatively constant internal conditions that are suitable for metabolism. Maintenance of a steady internal state is called *homeostasis*.
6. Through their metabolic activities, all living systems show *regulated growth*—a carefully controlled increase in the number of molecules of which they are composed.
7. During *reproduction*, organisms produce copies of themselves, which can show considerable variation. Modes of reproduction vary widely among organisms.

8. Reproduction with change produces *adaptations* that enhance an organism's survival and reproductive success in a particular environment.
9. A theory to explain adaptation was first proposed by *Charles Darwin* and *Alfred Russel Wallace* in the 1850's.
10. The objects that biologists study, from molecules to ecosystems, can be organized into a hierarchy in which each level consists of the objects at the next lower level.
11. *Molecules* are the smallest objects studied by biologists. The most important large molecules found in living systems are *proteins*, *nucleic acids*, *lipids*, and *carbohydrates*.
12. Molecules aggregate to form complex structures, like membranes, that have unique properties of their own.
13. The *cell* is the simplest unit capable of independent existence and reproduction. All organisms are cells or are composed of cells.
14. Structurally similar cells can associate to form *tissues*, and different tissues can aggregate to form *organs*.
15. The *organism* is the smallest unit of life. Organisms can be composed of a single cell (*unicellular*) or many cells (*multicellular*).
16. A group of structurally and functionally similar organisms that can interbreed with each other but not with other organisms is called a *species*.
17. Individuals of the same species living in a defined area are a *population*.
18. *An ecological community* consists of populations of different species living together in a particular environment.
19. Major types of ecological communities are *biomes*. All of the world's biomes form the *biosphere*.
20. *Emergent properties* are the new features of a system that result from the interaction of the system's components.
21. *Science* is both a collection of discovered knowledge about the universe and a process that can be used to discover new knowledge.
22. To discover new truths, scientists employ a cyclical process called the *hypothetico-deductive method* consisting of four steps: (1) making *observations*, (2) forming a *hypothesis*, (3) using the hypothesis to make *predictions*, (4) testing the predictions.
23. A hypothesis is a tentative answer to a question that usually predicts a specific effect. The corresponding *null hypothesis* states that the proposed effect is absent.
24. Assumptions and prior knowledge are usually involved in the formulation of a hypothesis.
25. In *experimentation*, extraneous factors are kept constant so that the effects of a single factor or group of related factors can be examined more clearly.
26. Greater control of environmental variables is possible in laboratory experimentation, but it is sometimes difficult to apply the results to nature. Field experimentation is less controlled, but the results may be easier to interpret.
27. A hypothesis cannot be proved or disproved with absolute certainty.
28. A *theory* is a hypothesis that has been extensively tested.

Questions (for answers and explanations, see page 46)

1. Which of the following is *not* a characteristic of all living systems?
   a. Regulated growth
   b. Autotrophism
   c. Metabolism
   d. Reproduction
   e. Adaptation

2. Which of the following is *not* a step in the hypothetico-deductive method of science?
   a. Stating hypotheses
   b. Making observations
   c. Establishing a conclusion with absolute certainty
   d. Deriving predictions from hypotheses
   e. Testing hypotheses

3. In the space provided before each of the following objects, provide a number that indicates the place of each object in a hierarchy from the least to most inclusive category. In the space following each object, specify its category.

   _____ A sperm ____________________

   _____ A mouse ____________________

   _____ Glucose ____________________

   _____ A lung ____________________

   _____ The Earth ____________________

   _____ A woodland ____________________

   _____ *Peromyscus leucopus* ____________________

4. Biological membranes are composed of molecules called proteins and phospholipids. Which of the following statements best describes an emergent property at the level of biological membranes?
   a. All cells are bounded by membranes.
   b. Membranes regulate what chemicals can pass into or out of the cell.
   c. Phospholipids are composed of phosphorus and lipids.
   d. Phospholipids and proteins are found in all cells.
   e. Cells contain membrane-bounded structures called organelles.

5. In reference to the studies done on palatability of cryptic and conspicuous caterpillars described in the text, classify each of the following as either an *observation*, a *hypothesis*, a *null hypothesis*, a *prediction*, a *result*, or an *assumption*.
   a. Birds are visually oriented predators: ______________
   b. Conspicuous caterpillars tend to occur in groups: ______________
   c. Bird 1 consumed five conspicuous and one cryptic caterpillars: ______________
   d. This species of conspicuous caterpillar should not be eaten by blue jays: ______________
   e. Blue jays should eat equal numbers of conspicuous and cryptic caterpillars: ______________

6. What do laboratory and field experiments have in common and how do they differ?

WHY PEOPLE DO SCIENCE • SIZE SCALES • TIME SCALES • MAJOR ORGANIZING CONCEPTS IN BIOLOGY • EVOLUTIONARY CONCEPTS • LIFE'S SIX KINGDOMS • SCIENCE AND RELIGION (pages 9–15)

Key Concepts

1. The volume of an object approximates the cube of its linear dimension; e.g., the volume of a cube with an edge of 10 μm equals $(10\ \mu m)^3$ or $1{,}000\ \mu m^3$.
2. The surface area of an object approximates the square of its linear dimension; e.g., the surface area of a cube with an edge of 10 μm equals $6(10\ \mu m)^2$ or $600\ \mu m^2$.
3. The rate of metabolism of an organism is a function of its *volume*, while the rate of heat and material exchange between an organism and the environment is a function of the *surface area* of the organism.
4. As an object increases in size, its volume increases more rapidly than its surface area; as an object decreases in size, its volume decreases more rapidly than its surface area.
5. As a cell increases in size, its metabolic need for exchange of heat and materials with the environment outstrips its ability to provide this exchange because of its limited surface area.
6. *Multicellularity* and the evolution of *specialized cells* overcomes some of the size limitations imposed on unicellular organisms by surface-to-volume ratios.
7. Large organisms have lower metabolic rates than small organisms because their large volume (mass) produces more heat than a smaller organism. However, the proportionally smaller surface area of a large organism can dissipate less heat than can that of a smaller organism.
8. Large organisms tend to have proportionally larger supporting appendages than small organisms because body weight increases in proportion to body volume, whereas the strength of appendages is proportional to their cross-sectional area.
9. Biologist are concerned with size because it influences where and how an organism lives, what it can eat, and its abundance.
10. The age of evolutionary events can be determined relatively by studying the location of fossils within known rock strata, or absolutely by measuring the decay of naturally occurring radioactive elements.
11. Studies of physiological and biochemical processes are expressed in units ranging from milliseconds to a year. Studies of aging may span an organism's life time.
12. Studies of populations are expressed in units ranging from hours to many years.
13. Microevolutionary time, expressed in units of thousands of years, is appropriate for studying changes in the genetic makeup of populations.
14. Macroevolutionary time, expressed in units of millions of years, is appropriate for studying long-term changes in the evolution of groups of organisms.
15. All phenomena associated with living systems can be explained with the laws of *chemistry* and *physics*.
16. Organisms are living systems adapted for capturing *energy* from the environment and converting it into biologically useful forms.
17. Living systems contain *genetic information* that is passed from one generation to the next and directs the production of new individuals.
18. The *cell theory* states that all living systems are composed of cells, and that all cells are derived from preexisting cells.
19. *Evolution* by *natural selection* produces organisms that are better adapted to their environment.
20. *Buffon* advanced the following arguments against the special creation of organisms: all mammals share the same limb bones, although the bones are modified for the functions they perform, and some mammals have limbs with functionless toes.
21. *Jean Baptiste de Lamarck* argued that due to use or disuse structures become modified, and that these modifications are passed on to future generations.
22. Charles Darwin's theory of evolution (also independently developed by Alfred Wallace) is based on the ideas that Earth is very old, all organisms are related by common descent, diversity results from speciation, evolution produces gradual changes in populations, and that evolution occurs by natural selection.
23. Evolution by natural selection is based on two observations: that considerable variation exists among individuals of the same species and that most species have high reproductive rates.
24. The major inference of Darwin's theory is that slight variation among individuals can lead to differential reproductive success, in which the more fit individuals leave more offspring than the less fit individuals.
25. Differential reproductive success by individuals better adapted for their environment is called *natural selection*.
26. *Artificial selection* results from differential reproductive success as directed by humans and not the environment (as in natural selection).
27. The general world view, or *paradigm*, of biology holds that evolution is by natural selection, and that evolutionary change is not goal-directed.
28. In a common scheme for classifying organisms, all species are grouped into *six kingdoms*.
29. The kingdoms *Archaebacteria* and *Eubacteria* include all the single-celled *prokaryotic* organisms. Prokaryotic cells lack true nuclei and some other organelles.
30. *Eukaryotic* cells were formed when certain prokaryotes began permanently living inside other prokaryotes. Members of the other four kingdoms are or consist of eukaryotic cells.
31. The kingdom *Protista* generally includes single-celled, eukaryotic organisms.
32. The kingdom *Fungi* includes multicellular, heterotrophic organisms called molds, mushrooms, yeasts, etc., that obtain their nutrients by *absorption*.

33. The kingdom *Plantae* includes multicellular, autotrophic organisms called plants that obtain their nutrients by *photosynthesis*.

34. The kingdom *Animalia* includes multicellular, heterotrophic organisms called animals that obtain their nutrients by *ingestion*.

Questions (for answers and explanations, see page 46)

1. From the list of animals listed below, select the one expected to have the greatest total daily food intake.

____

From the list of animals listed below, select the one expected to have the greatest daily food intake per kg of body weight. ________________

horse — elephant — human — ostrich — hummingbird

2. If the length of a cube-shaped cell is doubled, then cell volume should increase by about
a. 2 times.
b. 4 times.
c. 8 times.
d. 16 times.
e. 32 times.

3. Which of the following would *not* help an organism overcome problems related to surface area-to-volume relationships?
a. Increasing surface area by developing infoldings
b. Increasing surface area by developing appendages
c. Maintaining the same size while becoming unicellular
d. Developing internal gas-filled cavities
e. Maintaining the same size while becoming multicellular with specialized cells

4. In describing the evolution of warm-bloodedness in mammals and birds, one would be mostly using
a. a physiological time scale.
b. a population time scale.
c. a microevolutionary time scale.
d. a macroevolutionary time scale.

5. Which of the following is *not* a major organizing principle of biology?
a. All living systems obey the laws of chemistry and physics.
b. All living systems consist of cells.
c. The genetic code consists of information specifying the construction of new individuals.
d. Evolution occurs by the inheritance of structures modified by use or disuse.
e. Living systems capture and transform energy into useful forms.

6. Which of the following was *not* a major hypothesis incorporated by the theory of evolution by natural selection advanced by Charles Darwin?
a. Earth is ancient.
b. Evolution proceeds by the accumulation of gradual changes within populations.
c. Offspring inherit genes from their parents.
d. Biological diversity is produced by speciation.
e. All present-day organisms have a common ancestor in the past.

7. Which of the following kingdoms consists of organisms that are mostly unicellular and have eukaryotic cells?
a. Eubacteria
b. Protista
c. Fungi
d. Plantae
e. Animalia

8. Which of the following kingdoms consists of organisms that are mostly multicellular, photosynthetic autotrophs?
a. Eubacteria
b. Protista
c. Fungi
d. Plantae
e. Animalia

9. Which of the following kingdoms consists of organisms that are mostly multicellular, absorptive heterotrophs?
a. Archaebacteria
b. Protista
c. Fungi
d. Plantae
e. Animalia

10. Describe natural selection and how it differs from artificial selection.

11. Describe a hypothesis for the evolution of the eukaryotic cell.

2

Small Molecules

CHAPTER LEARNING OBJECTIVES—after studying this chapter you should be able to:

- ❑ Describe the structure of the atom, in terms of the locations of protons, electrons, and neutrons and the distribution of mass and charge.
- ❑ Relate an element's atomic number, mass number, and chemical properties to the number of protons, electrons, and neutrons in its atoms.
- ❑ Write the symbols, atomic numbers, and mass numbers of the biologically important elements using the conventions described in the text.
- ❑ Explain how isotopes of an element differ in terms of atomic number and mass number and how an element's atomic weight is determined.
- ❑ Describe how an element's isotopes can be separated and how the liquid scintillation and autoradiography methods are used to detect radioisotopes.
- ❑ Describe the concept of half-life and its use in radioisotope aging of biological materials.
- ❑ Describe the distribution of elections in an atom's orbitals and shells and how this distribution determines the chemical properties of atoms.
- ❑ Differentiate between molecules and ions and covalent and ionic bonds.
- ❑ Use the covalent bonding capabilities of biologically important elements to determine the types of chemical bonds they will form.
- ❑ Differentiate between compounds and elemental substances.
- ❑ Relate molecular and structural formulas for biologically important compounds.
- ❑ Determine molecular weight and understand its relationship to the concept of molarity.
- ❑ Relate equations showing biologically important chemical reactions to changes in chemical bonding between reactants and products.
- ❑ Explain what a calorie and kilocalorie are and how they are used to represent chemical bond energy.
- ❑ Describe the biologically important properties of water.
- ❑ Understand the concept of pH, relate it to the $[H^+]$ and $[OH^-]$, and given the pH of an aqueous system, be able to determine if it is acidic, basic, or neutral.
- ❑ Identify an acid and a base given a reversible chemical reaction that affects the pH of an aqueous system.
- ❑ Explain what a buffer is and how a buffer can maintain a relatively constant pH within a buffering range.
- ❑ Explain the concept of polarity and be able to identify compounds as polar or nonpolar.
- ❑ Describe the biological consequences of water's polar nature and its ability to form hydrogen bonds with other molecules.
- ❑ Explain the similarities and differences between van der Waals and hydrophobic interactions and the biological importance of these two forces.
- ❑ Recognize the distinguishing features of the following organic compounds: saturated and unsaturated hydrocarbons, alcohol, aldehyde and ketone, organic acid, organic base, and amino acid.
- ❑ Recognize the distinguishing features of the following functional groups: hydroxyl, carbonyl, carboxyl, amino, phosphate, and sulfhydryl.
- ❑ Explain the terms "isomer" and "optical isomer" and be able to identify an asymmetric carbon atom.

ATOMS • ELEMENTS (pages 19–22)

Key Concepts

1. *Atoms* are made of the elemental particles *protons*, *neutrons*, and *electrons*.
2. Protons and neutrons are found in the *nucleus* of the atom and represent most of the mass of the atom.
3. Electrons are found in *orbitals* surrounding the nucleus.
4. Protons and neutrons have the same mass; each is equal to one atomic mass unit (a.m.u) or *dalton*.
5. Protons have a charge of +1 unit, electrons have a charge of −1 unit, and neutrons are electrically neutral.
6. Atoms are electrically neutral because they contain the same number of electrons and protons.
7. A *chemical element* cannot be changed by chemical means into a simpler substance.
8. An element's chemical properties are determined by the number of electrons it contains.
9. The *atomic number* of an element is the number of electrons or protons present in its atoms.

10. All of the atoms of a chemical element have the same atomic number and the atomic number differs for each element.
11. The *mass number* is equal to the sum of the protons and neutrons in the nucleus of the atom; the mass of the electrons is negligible and is ignored.
12. Common notation for representing elements uses a one- or two-letter symbol with, optionally, the atomic number shown as a subscript and the mass number as a superscript preceding the symbol.

$$^{\textit{mass number}}_{\textit{atomic number}}\text{SYMBOL}$$

as in $^{12}_{6}C$ for carbon and $^{40}_{20}Ca$ for calcium.

13. Atoms with the same atomic number but a different mass number are *isotopes* of an element. Specifically, the isotopes of an element differ in the number of neutrons present.
14. Isotopes are usually shown with only the mass number preceding the symbol, as in ^{12}C and ^{14}C for two of carbon's isotopes.
15. The *atomic weight* of an element is the average of the mass numbers for all isotopes of an element weighted according to the natural occurrence of each isotope.
16. *Radioisotopes* undergo radioactive decay to become another element by giving off energy or elementary particles. Radioisotopes are used as markers in biological research. Isotopes of this type include ^{3}H, ^{14}C, ^{32}P.
17. *Liquid scintillation* and *autoradiography* are two common methods for detecting radioactivity in biological samples.
18. Each radioisotope loses one-half of its radioactivity in a constant time period called its *half-life*. The regularity of decay of a radioisotope allows it to be used in determining the age of biological materials.
19. *Stable isotopes* are nonradioactive but can be detected by their mass difference using an instrument called a *mass spectrometer*. Biologically important stable isotopes include ^{2}H and ^{18}O.

Questions (for answers and explanations, see page 47)

1. Which of the following statements about atomic structure is *not* true?
   a. Almost all the mass of an atom resides in the nucleus.
   b. Electrons are in orbitals that surround the nucleus.
   c. Protons and neutrons have approximately the same mass.
   d. All atoms contain electrons, protons, and neutrons.
   e. Protons and electrons have equal and opposite charge.
2. Which of the following statements about elements is *not* true?
   a. Elements cannot be changed by chemical means into simpler substances.
   b. The mass number of an element equals the number of protons plus neutrons.
   c. The atomic number of an element equals the number of electrons or protons.
   d. All atoms of an element have the same atomic number.
   e. All atoms of an element have the same mass number.
3. The mass number minus the atomic number
   a. is equal to the number of electrons in the atom.
   b. is equal to the number of protons in the atom.
   c. is equal to the number of neutrons in the atom.
   d. is equal to the atomic weight of the atom.
   e. is the same for all isotopes of an element.
4. There are two isotopes of a hypothetical element X: ^{30}X and ^{32}X. If the atomic weight of X is 30.5, what is the natural proportion of ^{30}X to ^{32}X in the world?
   a. 100:1
   b. 50:50
   c. 75:25
   d. 25:75
   e. 1:100
5. Isotopes of the same element can be physically separated based on
   a. electric charge differences.
   b. mass differences.
   c. radioactivity.
   d. atomic number.
   e. differences in chemical properties.

Activities (for answers and explanations, see page 47)

- Write the symbols for the most common isotopes of the following elements, showing the atomic number and mass number, using the notation described in key concept 12.

Hydrogen **Carbon**

Nitrogen **Oxygen**

Sulfur **Phosphorus**

- Write the names and symbols for the less common, but biologically important, isotopes of hydrogen, carbon, and oxygen.

Hydrogen

Carbon

Oxygen

- Write the numbers of electrons, protons, and neutrons found in atoms of each of the following elements or isotopes.

	Electrons	Protons	Neutrons
$^{1}_{1}H$			
$^{14}_{6}C$			
$^{14}_{7}N$			
$^{65}_{30}Zn$			

THE BEHAVIOR OF ELECTRONS • CHEMICAL BONDS (pages 22–26)

Key Concepts

1. *Chemical reactions* occur when electrons are exchanged or shared differently between atoms.
2. An *electron orbital* is a region of space where an electron is located at least 90% of the time. A maximum of two electrons can occupy an orbital, and the two electrons spin in opposite directions.
3. Orbitals are grouped into *shells* that surround the nucleus and are designated by the letters K, L, M, N, O, P, and Q from the innermost to the outermost shell.
4. The *K shell* has a single spherical orbital (*s* orbital) holding a maximum of two electrons.
5. The *L shell* has four orbitals, a spherical *s* orbital and three dumbbell-shaped *p* orbitals oriented in the x, y, and z axes relative to the center of the nucleus. The L shell accommodates a maximum of eight electrons (two per orbital).
6. Successive shells (M–Q) are located at increasing distance from the nucleus and hold differing numbers of orbitals.
7. Atoms are most stable when each shell has a complete complement of electrons.
8. The energy level of electrons increases with their distance from the nucleus. Therefore, electrons in outer shells have more energy than electrons in more inner shells. Electron shells are filled from the innermost shell outward.
9. The outermost shell of an atom determines the chemical reactivity of the atom.
10. An atom with its outermost shell completely filled is most stable and, thus, least reactive with other atoms. Elements with completely filled shells are called the *inert elements* and include helium (He), neon (Ne), argon (A), and krypton (Kr).
11. A *molecule* consists of two or more atoms linked together by chemical bonds (attractive forces that hold the atoms together).
12. A *covalent chemical bond* results when two atoms share electrons in order to complete their outermost shell.
13. For an atom that can form covalent bonds, the number of vacant positions in its outer shell is the number of covalent bonds that it can form.
14. The *covalent bonding capabilities* of several biologically important elements include:

Hydrogen ($_1H$)	1
Oxygen ($_8O$)	2
Nitrogen ($_7N$)	3
Carbon ($_6C$)	4
Sulfur ($_{16}S$)	5 or 2

15. A single bond results if two atoms share a pair of electrons, a double bond results when four electrons are shared, and a triple bond results when six electrons are shared by two atoms.
16. Atoms that complete their outer shells by sharing electrons are stable because the attraction of the shared electrons for the nuclei of the atoms exactly balances the mutual repulsion of the nuclei.
17. *Ions* are atoms or groups of atoms that have gained or lost electrons and, as a result, are electrically charged. Positively charged ions are *cations*; negatively charged ions are *anions*.
18. Some covalently bonded molecules form ions when they dissolve in water.
19. When a molecule ionizes it forms positively and negatively charged ions whose total charge is zero, as in
$HCl \rightarrow H^+ + Cl^-$.
20. Some ions have multiple charges, as in Ca^{2+}, Fe^{3+}, and Al^{3+}. Groups of atoms can be ions, as in NH_4^+, SO_4^{2-}, and PO_4^{3-}.
21. Oppositely charged ions can be bound together to form *ionic compounds* such as common salt (NaCl).
22. An *ionic bond*, resulting from the electric attraction between oppositely charged ions, is less than one-tenth as strong as a covalent bond.

Questions (for answers and explanations, see page 47)

1. Sodium has an atomic number of 11. How many electrons are located in its M shell?
a. 1
b. 2
c. 7
d. 8
e. 0

2. Neon has an atomic number of 10. It is chemically ________ and has ____ completely filled orbitals in its L shell.
a. reactive, 2
b. reactive, 3
c. reactive, 4
d. inert, 2
e. inert, 3
f. inert, 4

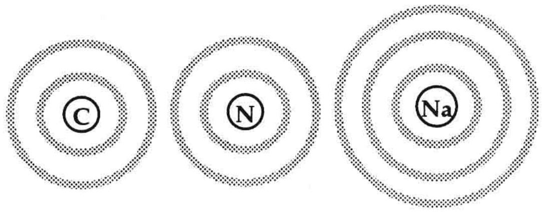
3. If carbon can form the following stable molecule with Z, Z=C=Z, which of the following could be the atomic number of Z?
a. 2
b. 6
c. 8
d. 10
e. 11

4. The element with which of the following atomic numbers would be *most* stable?
a. 1
b. 3
c. 12
d. 15
e. 18

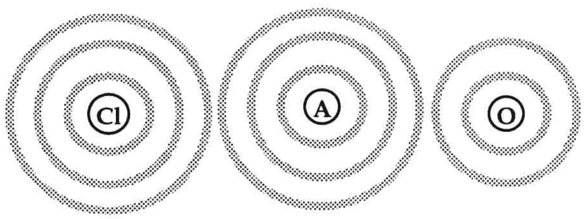
5. Given that the chemical properties of an element are determined by the number of electrons in its outer shell, which of the following pairs of elements would have the most similar chemical properties?
a. Carbon ($_6C$) and Nitrogen ($_7N$)
b. Carbon ($_6C$) and Oxygen ($_8O$)
c. Helium ($_2He$) and Fluorine ($_9F$)
d. Fluorine ($_9F$) and Chlorine ($_{17}Cl$)
e. Chlorine ($_{17}Cl$) and Sodium ($_{11}Na$)

Activities (for answers and explanations, see page 47)

- In the following figures, place electrons in the appropriate shells based on the atomic numbers of the elements carbon ($_{6}C$), nitrogen ($_{7}N$), and sodium ($_{11}Na$).

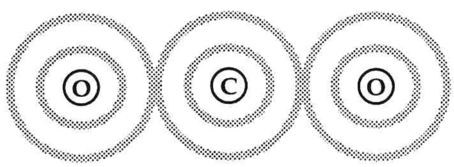


- In the following figures, place electrons in the appropriate shells based on the atomic numbers of the elements chlorine ($_{17}Cl$), argon ($_{18}A$), and oxygen ($_{8}O$).

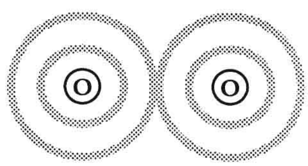


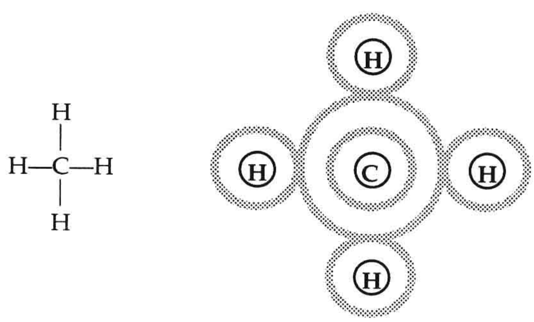
- In the following figures, place electrons in the appropriate locations based on the covalent bonding shown for each molecule.

O═C═O



O═O





MOLECULES • CHEMICAL REACTIONS • WATER • ACIDS, BASES, AND pH • BUFFERS (pages 26–30)

Key Concepts

1. *Compounds* are substances whose molecules have two or more different atoms linked together by a chemical bond; *elemental substances* are composed of only one type of atom.
2. The *molecular formula* shows the symbols for each atom followed by the numbers of each atom written as a subscript, as in H_2O. *Structural formulas* show how the atoms are linked together.
3. The *molecular weight* of a compound is the sum of the atomic weights of the atoms in the molecule.
4. A gram molecular weight of a substance (its molecular weight in grams) is called a *mole*. If one mole is dissolved in one liter of water, the resulting solution is a 1.0-*molar* solution.
5. A mole of any substance contains the same number of molecules, called *Avogadro's number*, or 6.023×10^{23} molecules per mole.
6. A *chemical reaction*, represented by an arrow →, occurs when atoms change their pattern of electron sharing with other atoms.
7. Chemical reactions usually result in an exchange of energy with the environment. Some reactions release energy, while other reactions absorb it.
8. A *calorie* (cal) is the amount of heat required to raise 1 gram of water from 14.5 to 15.5°C. A *kilocalorie* (kcal) equals 1,000 cal.
9. Calories can be used as a measure of the energy associated with a chemical bond. In a chemical reaction, the bond energy of the reactants is usually different than the bond energy of the products.
10. More substances can dissolve in water than in any other solvent.
11. Most biologically important chemical reactions take place in water-based or *aqueous* solutions.
12. Ice floats because it is less dense than liquid water. This prevents bodies of water from freezing solid.
13. Water uses significant heat as it changes from liquid to gas (*evaporation*). Evaporation of sweat is an efficient cooling process for some organisms.
14. It requires a relatively large amount of heat to raise the temperature of water. This property causes the temperature of bodies of water to remain relatively constant or to change only slowly.
15. About 1 in every 550 million water molecules ionizes into a hydrogen ion (H^+) and a hydroxide ion (OH^-), $H_2O \rightarrow H^+ + OH^-$.
16. Pure water has equal concentrations of hydrogen and hydroxide ions and is called *neutral*. A solution with more hydrogen ions than hydroxide ions is called *acidic*. A solution with more hydroxide ions than hydrogen ions is called *basic* or *alkaline*.
17. A compound that releases H^+ in water is called an *acid*. Carbonic acid is an example: $H_2CO_3 \rightarrow H^+ + HCO_3^-$. Adding an acid to water makes the solution *acidic*.
18. A compound that accepts H^+ is called a *base*. The bicarbonate ion is an example of a base: $HCO_3^- + H^+ \rightarrow H_2CO_3$. Adding a base to water makes the solution *basic* or *alkaline*.
19. Acids and bases occur in pairs. H_2CO_3 is an acid; bicarbonate ion, HCO_3^-, is a base. $HCO_3^- + H^+ \rightleftharpoons H_2CO_3$ is an example of a *reversible reaction*, as indicated by double arrows.