STUDY GUIDE

to accompany

ESSENTIALS OF BIOLOGY

Hopson & Wessells

Deborah M. Brosnan / Janet L. Hopson

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Cover photo: Red-eyed leaf frog
(*Agalychnis callidryas* on *Heliconia mathiasii*)
by Michael Fogden

TO THE STUDENT

You have embarked upon a fascinating voyage—the study of biology. This is truly a voyage of discovery, encompassing topics from the early evolution of life on Earth to the complex social and environmental factors that affect life forms on our planet today. We have designed this Study Guide to supplement your text, and help you make the most of this journey. Use it effectively, and you will find it easier to learn and retain the facts and concepts of biology, you will perform better on tests, and you will develop a lasting understanding of the "science of life."

Each chapter in the Study Guide follows the corresponding text chapter, and is divided into six parts:

Chapter at a Glance A quick recap of the text chapters's main sections.

Perspective An introductory survey of the most important chapter facts and concepts, with hints about potential trouble areas and topics that may require special attention. This section also points out concepts that will be importanat in other chapters. If you read **Perspective** before you begin studying your text, you will get the most out of your hard work.

Learning Objectives A specific list of learning goals to keep in mind as you study—a useful tool to help you focus your time on key material in the chapter.

Chapter in Review A concise summary of every main section in the text chapter. Although no substitute for the text, this section serves both as an overview that emphasizes key concepts, and as a focused review before tests.

Key Terms All the most important vocabulary from the text chapter. To use this list as a study exercise, write a definition for each term and then check your work against the text.

Self-Quiz A comprehensive combination of questions and problems that enable you to test your mastery of facts, concepts, and vocabulary. This section includes matching and completion exercises, true/false and short-answer questions, and a multiple choice review. Some questions involve simple recall, while others require you to analyze situations and integrate related facts and concepts. Many chapters also have an **Exercise** based on text art or tables designed to reinforce your understanding of basic biological processes. An **Answer** section at the back of your Study Guide gives the answers to Self-Quiz questions and page references for short-answer items.

Acknowledgements

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Deborah M. Brosnan

CONTENTS

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THE STUDY OF LIFE

CHAPTER AT A GLANCE

PERSPECTIVE

The first chapter in this book begins by asking what, exactly, is life? It then describes seven main criteria that scientists use to distinguish living from nonliving. In this chapter you will learn about the pioneering work of Darwin and Wallace in developing the theory of evolution by natural selection. Finally you will encounter the biologist's most cherished tool—the scientific method. It is important to understand the method's principles and how they are used, because you will confront them again and again as you proceed through this course.

LEARNING OBJECTIVES

When you have mastered the concepts of this chapter, you will be able to:

1. List the seven characteristics of life.
2. Explain why evolution can be pictured as a branching tree.
3. Identify Francesco Redi and Louis Pasteur, and describe their experiments.
4. Briefly discuss the lives of Charles Darwin and Alfred Russel Wallace, and outline the two theories of evolution by natural selection.
5. Outline the scientific method, and explain the differences between hypotheses, theories, and natural laws.
6. Explain the difference between inductive and deductive reasoning.
7. Explain how the scientific method is relevant to daily decision making and how it applies to ethical and social problems.

CHAPTER REVIEW

What Is Life?

Whether a single cell or a higher plant or animal, every living organism has seven basic characteristics: a complex organization, the ability to take in and use energy, the ability to grow and develop, the ability to reproduce, adaption to its environment and way of life, variation based on heredity, and responsiveness to the environment. A very important feature of all living forms is their past history; every living thing is a descendent of a previously living ancestor.

Life on Earth: A Brief History

For many centuries people believed in **spontaneous generation**, the continuous origin of new life forms. It was not until the experiments of Pasteur in the mid-nineteenth century that this concept was finally put to rest. Today scientists believe that life on earth arose about 4 billion years ago. Energy from the sun and earth led to the formation of complex chemicals from atoms and simple molecules. These chemicals aggregated to form the first cells, the basic units of life that are able to reproduce. Imperfections in reproduction have given rise to the great diversity of life on earth today. Despite this all living forms share fundamental chemical traits, including *deoxyribonucleic acid* (DNA) and *adenosine triphosphate* (ATP).

Evolution: A Theory That Changed Biology and Human Thought

In the nineteenth century Charles Darwin and Alfred Russel Wallace simultaneously and independently proposed the **theory of evolution by natural selection.** This theory has proved to be one of the most unifying concepts in **biology**, the study of living organisms. It was revolutionary in proposing a mechanism for evolution—the mechanism of natural selection. According to the theory individuals show heritable variation, and this variation gives rise to some individuals that are better adapted to their environment than are others. Such better-adapted individuals tend to leave more offspring, thereby contributing proportionately more genes to later generations. Through this mechanism of differential survival and reproduction, natural events "select" the individuals best adapted to various environments.

The Scientific Method: One Approach to Extending Knowledge

The scientific method provides the basis for a scientific study of nature. It begins with observations and the establishment of basic facts. Through **inductive reasoning** scientists then formulate a **hypothesis**—an educated guess—that will explain those observations. Once a hypothesis has withstood repeated attempts to falsify it, it can qualify as a theory. This testing process relies on **control experiments** in which conditions are imposed that differ from the ones set forth in the hypothesis under examination.

A **theory** is a general statement of how a process works. Usually it is based on a number of thoroughly tested hypotheses. Once a theory exists, it can be used for **deductive reasoning**—that is, for making predictions on the basis of what is already known. For example, the gas carbon dioxide (CO_2) is formed under certain conditions by one atom of carbon and two atoms of oxygen. Thus, if we provide the right atoms and conditions in the future, we expect (predict) that, as we have seen many times in the past, CO_2 will be formed. When a theory is repeatedly tested and corroborated in this way—as has happened with the theory of evolution—it becomes a **natural law**, accepted as scientific fact.

Biology, Society, and Your Future

The scientific method cannot provide answers to the moral and ethical dilemmas raised by modern advances in science, such as recent developments in genetic engineering. However, it can provide a framework for rigorous, logical thinking to help people in many walks of life make decisions.

KEY TERMS

biology
control experiment
deductive reasoning
hypothesis
inductive reasoning
natural law
scientific method
spontaneous generation
theory
theory of evolution
theory of natural selection

SELF-QUIZ: TESTING WHAT YOU HAVE LEARNED

Key Terms: Matching

Match each term on the left with the most appropriate description on the right.

1. inductive reasoning	a. predicting new facts
2. theory	b. educated guess
3. life	c. grows and reproduces
4. control experiment	d. Charles Darwin
5. theory of evolution	e. organized common sense
6. natural selection	f. general statement
7. natural law	g. scientific fact
8. spontaneous generation	h. life from nonlife
9. deductive reasoning	i. conditions different from hypothesis
10. scientific method	j. better-adapted individuals survive
11. hypothesis	k. specific to general

True or False?

1. _____ The scientific method is useful in daily decision making.
2. _____ Evolution is essentially a form of history.
3. _____ Francesco Redi convinced scientists of his time that spontaneous generation was false.
4. _____ The secret to Pasteur's success was his use of a straight-necked flask.
5. _____ Cells are the fundamental units of life.
6. _____ Buffon believed in special creation, and denied that all life is related.
7. _____ Darwin sailed on the HMS Hornblower in 1831.
8. _____ Darwin based his theory of evolution by natural selection in part on the results of animal domestication.
9. _____ Thomas Malthus believed that organisms never reproduce fast enough.
10. _____ Scientific tests are designed to prove hypotheses.

Completion

1. The fundamental units of all living things are _____________.
2. The idea that an organism could acquire a characteristic during its lifetime and then pass that characteristic on to its offspring was formulated by _____________.
3. Answers to scientific problems, or explanations of a certain set of phenomena, are formulated as a _____________.
4. Organisms interact and influence one another in a process called _____________.
5. When a theory is shown to withstand numerous tests, it may be elevated to the status of a _____________ _____________.
6. The form of reasoning wherein predictions are made on the basis of observed and tested theories is called _________________________.
7. Darwin and Wallace proposed the theory of _____________ _____________ as a mechanism for evolution.

Short Answer

1. Define *life,* using the seven characteristics of living things.

2. How did the work of Redi (and later Pasteur) weaken the notion of spontaneous generation?

3. What were the two main ideas proposed by Lamarck in his systematic theory of evolution?

4. What were Darwin's two major theories?

5. Compare and contrast inductive and deductive reasoning.

6. What is a control experiment?

7. Is there any place in science for morality?

Multiple Choice Review

Finish each of the following sentences by circling the letter of the correct response.

1. The idea that living arises from nonliving is known as
   a. Lamarckism
   b. spontaneous generation
   c. natural selection
   d. evolution
   e. none of the above

2. Pasteur's experiment with a specially constructed flask was designed to
   a. demonstrate spontaneous generation
   b. disprove the belief that life-giving forces were found in air
   c. disprove natural selection
   d. show natural selection in a laboratory
   e. disprove Lamarck's theories

3. The earth's atmosphere is well suited to life because
   a. it screens out much UV radiation from the sun
   b. it allows most UV radiation to penetrate to the earth's surface
   c. it maintains a surface temperature ranging approximately from 0–100°C
   d. b and c
   e. a and c

4. About 4 billion years ago, the sun's energy and heat from the earth are believed to have facilitated
   a. the formation of the earth's atmosphere
   b. the formation of complex compounds from atoms and simple molecules
   c. meteorite showers
   d. the earth's gravity
   e. none of the above

5. The great variety of life on earth is partly the result of
   a. imperfections in the hereditary process
   b. spontaneous generation
   c. the perfect nature of the hereditary process
   d. meteorites bombarding earth at an early point in its history
   e. none of the above

6. Charles Darwin and Alfred Russel Wallace's theory of evolution offered a reasonable mechanism according to which life could change by virtue of heritable (genetic) variation. This theory depends upon
   a. spontaneous generation of the first life
   b. a control experiment
   c. the presence of water and an atmosphere
   d. different rates of reproduction and survival
   e. the survival of acquired characteristics

7. Testing of a scientific hypothesis is best accomplished by attempting to
   a. prove the hypothesis
   b. select good evidence that proves the hypothesis
   c. call it a theory
   d. falsify the hypothesis
   e. duplicate the work

8. Ironic as it may seem, the scientific work of Francesco Redi was actually hampered by the invention of the microscope, because
   a. it allowed his critics to falsify his experiments
   b. it allowed even more organisms, which apparently arose from nowhere, to be seen
   c. it showed that Pasteur was wrong
   d. it showed that his flasks actually held small cells
   e. none of the above

9. One of the most important reasons why earth can harbor life is that water exists here as a liquid. This would not be possible if earth's temperature ranged
   a. much below 0°C or above 100°C
   b. below 32°C or above 100°C
   c. below 32°C or above 98.8°C
   d. much below 0°C or above 98.8°C
   e. none of the above

10. Buffon reputedly believed in spontaneous generation but puzzled over the presence of "functionless" appendages. He concluded that
    a. spontaneous generation is a fact of life
    b. the basic limb design was modified and therefore all vertebrates have a common ancestor
    c. he had evidence for natural selection
    d. Lamarck's theory of evolution was correct
    e. Darwin's and Wallace's theory was incorrect

11. Once a scientific theory has withstood numerous tests and accurately predicted future observations, it may be elevated to the level of
    a. an idea
    b. a hypothesis
    c. a natural law
    d. an example of deductive reasoning
    e. none of the above

Exercise

Fill in the following table, using your text as a guide.

The Seven Characteristics of Life

Characteristic	Example

2
Atoms, Molecules, and Life

CHAPTER AT A GLANCE

PERSPECTIVE

Life processes are driven by **chemical reactions**—the interactions that occur between atoms and molecules. This chapter focuses on the structure of atoms and the type of bonds formed when atoms interact. Be sure you understand the principles that underlie ionic, covalent, and polar bonding. These bonds form the basis for the biochemical reactions that govern life processes, and you will find them memtioned frequently in the course of this book. The last section of this chapter considers life as a continuum of organized physical matter from atoms to molecules to cells and organisms.

LEARNING OBJECTIVES

When you have mastered the concepts of this chapter, you will be able to:

1. Define the terms **element** and **atom**, and distinguish between the two.
2. List the types of subatomic particles, and explain how they interact to form atoms.
3. Define the term **atom** with reference to atomic orbitals and their energy levels.
4. Explain the four rules of electron orbitals and their corresponding energy levels.
5. Explain how atoms bond to form elements and compounds.
6. Name the three basic types of bonds, explain how they are formed, and compare their strengths.
7. Explain the meanings of chemical formulas and equations, and describe what they tell us about reactants and products.
8. List the physical properties of water, and explain their causes.
9. Describe and explain the dissociation of water.

CHAPTER REVIEW

Elements and Atoms: Building Blocks of All Matter

Elements are the fundamental substances of the universe. This means that they are composed exclusively of **atoms** of a single kind. In general, an element's atoms cannot be changed in any way—either added to or subtracted from—without changing the nature of the element.

An atom has structure, a central nucleus composed of positively charged **protons** and uncharged **neutrons** surrounded by negatively charged **electrons** that orbit the nucleus in specific pathways. The important characteristics of atoms are largely determined by these three major types of particles. An atom's **atomic number** is equal to the number of its protons, while the **atomic weight** or **mass** is simply the number of protons added to the number of neutrons. **Isotopes** of elements share the same atomic number but have different atomic weights.

Atoms are electrically neutral because the negatively charged electrons are equal in number to the positively charged protons in the nucleus. The space within which the electrons move about the nucleus is called an **orbital**, and electrons are distributed throughout an atom's orbitals in accordance with a basic set of rules stating that simpler, lower-energy-level orbitals must be filled before higher-energy-level orbitals are occupied..

Molecules and Compounds: Aggregates of Atoms

Two or more atoms bound together make up a **molecule**. Chemical bonding takes place when unpaired (valence) electrons in the outermost orbitals of atoms fuse into a shared molecular orbital. An atom can form as many bonds as there are unpaired electrons in its outermost orbital. The pairing of electrons in bonds forms an energetically stable unit.

Atoms may be held together by chemical bonds of three major types, and the kind of bond that holds together a molecule or compound has a direct bearing on the substance's properties. The first type, a **covalent bond**, forms when the electrons of one atom are shared with the electrons of another. In a single covalent bond, only one pair of electrons is shared; in double and triple bonds two and three pairs, respectively, are shared. Occasionally an electron is lost from the outermost orbital of a covalently bonded atom, resulting in a highly energized molecule known as a free radical.

An **ionic bond** forms when one atom gives up a valence electron and another adds the free electron to its outermost orbital. Atoms that have lost or gained electrons bear a charge and are called **ions**. In a third type of bond, called a **polar bond**, electrons are shared but tend to spend more time orbiting one nucleus than the other. The ability of an atom to attract electrons from other atoms in a molecule is called **electronegativity**. Water molecules (H_2O) are polar: the electrons spend more time orbiting the single oxygen nucleus than the two hydrogen nuclei.

The strength of a chemical bond, called **bond energy**, is the amount of energy (measured in **kilocalories**) needed to break it. All covalent and ionic bonds are **strong bonds**, because a great deal of energy is needed to break them. **Weak bonds**, including **hydrogen bonds** and van der Waals forces, are easily broken.

The numbers of different atoms that make up a molecule are expressed in the shorthand of a **molecular formula**. Molecules can also be represented by a **structural formula** that shows the rough arrangement of its various atoms in space and the number of bonds between them. The process in which molecules and ions (**reactants**) interact to form new substances (**products**) is called a chemical reaction.

Water: Life's Precious Nectar

Life on earth could not exist were it not for the presence of water in a liquid state. The physical properties of water include its high melting and boiling points, its high **specific heat** and **heat of vaporization**, and its **cohesion, tensile strength, adhesion, capillarity,** and **surface tension**. These properties derive from the structure of water molecules, as well as from the weak hydrogen bonds that water molecules tend to form with one another.

Water is earth's most widespread **solvent**; that is, a substance capable of forming a homogeneous mixture with molecules of another substance. Compounds that dissolve readily in water are termed **hydrophilic**; those that tend to be insoluble in water—because they contain atoms linked by nonpolar covalent bonds—are called **hydrophobic** compounds. Such compounds are basic to life on earth: a hydrophobic layer of lipids (a class of fats) covers the surface of every living cell.

A final, important property of water is dissociation—its slight tendency to fall apart, separating into hydrogen ions (H^+) and hydroxyl ions (OH^-). A **solute** in water that gives up (donates) H^+ ions is an **acid**, while compounds that decrease the amount of H^+ in solutions are **bases**. The **pH** scale expresses the concentration of H^+ in acid and base solutions. A solution with a pH of less than 7 is an acid, one with a pH greater than 7 is a base. A **buffer** is any chemical substance that binds H^+ when its concentration is high, and releases hydrogen ions when the concentration is low. Buffers are extremely important to cells and organisms because they help resist changes in pH when acids or bases are produced or added.

Atoms to Organisms: A Continuum of Organization

There is physical and chemical as well as biological evolution. The various elements that make up the earth and its life forms were formed shortly after the beginning of the universe and can be ordered into a sort of hierarchical classification, from subatomic particles to atoms to molecules and so on. The same kind of increase in complexity is seen in biological evolution. Thus we can view the world around us as a continuum of organization, from the simplest element to the most complex organism.

KEY TERMS

acid
adhesion
atomic number
atomic orbital
atomic weight
base
bond energy
buffer
capillarity