

FIFTH EDITION

# BIOLOGY OF ANIMALS



HICKMAN

ROBERTS

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*with 949 illustrations including 791 in color*



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To  
**The Animals, Great and Small,**  
*that enrich our lives and*  
*teach us so much about ourselves*

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#### FIFTH EDITION

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# Preface

*Biology of Animals* is a nonmajors and mixed-majors textbook designed for a one-semester course in general zoology. The book is organized into four parts, in which subject matter progresses from unifying general principles that govern the lives of all animals from paramecia to primates (Part One), to themes in animal form and function (Part Two), to an extensive, phylogenetically arranged survey of diversity in the animal world (Parts Three and Four). This was the successful organizational arrangement of the previous four editions of *Biology of Animals* and the preference of most instructors who have been contacted for their opinions. Each teacher will, of course, adapt the book to the particular needs of the class, selecting topics or rearranging the sequence as appropriate.

## CHANGES IN THIS EDITION

Although *Biology of Animals* has been through four well-received editions, this fifth edition was extensively reworked and revised. In producing this edition, we benefited from having just revised this book's larger sibling, *Integrated Principles of Zoology*, now in its eighth edition. Many of the improvements to that text, such as strengthened topical presentations, many new illustrations, and pedagogical aids, were carried over into this fifth edition of *Biology of Animals*. In addition, we carefully examined all aspects of the fourth edition to improve teaching and learning aids, update information, and revise old illustrations or add new ones. This task was vastly assisted by the suggestions of seven professional zoologists who read and commented on the entire text. The revision is too extensive to describe in detail, but some of the more important changes are highlighted here.

Part One is devoted to the broad underpinnings of biology, dealing with the general principles of cell biology, metabolism, genetics, evolution, and ecology — introductory material that applies widely, often universally, to the animal world. Basic chemistry in Chapter 1 is limited to what is essential for the material that follows. Several sections were reworked and a new section added that explains what zoology is and why an understanding of zoology helps us to understand ourselves. Chapter 2 covers cell structure, cell division, and cellular metabolism. Several sections were extensively rewritten, including the fluid-mosaic model of the plasma membrane and the role of glycoproteins, the cytoskeleton, and junctional complexes. Descriptions of diffusion and osmosis were clarified. To help the student understand the role and action of enzymes in cellular metabolism, sections on energy and life, free energy, and activation energy were added. Chapter 3 is a presentation of both classical and molecular genetics and includes a description of protein synthesis. Several sections were rewritten, and an important addition covers molecular genetics of cancer.

Chapter 4, the centerpiece of Part One, is intended as a readable and non-technical explanation of current evolutionary theory. Several sections were rewritten and many new illustrations added. Several changes were made in Chapter 5: the opening discussion of conditions for life on earth was substantially





shortened, and several sections were partly rewritten, including those on terrestrial biomes, the food chain, niche concept, and population growth.

Part Two deals with form and function in animals. In Chapter 6 the topics of animal architecture and of animal integument, support, and movement—treated in separate chapters in the fourth edition—have been combined into a single chapter. Some topics, particularly the introductory treatment of development and the explanation of basic animal body plans, have been moved to Chapters 13 and 14 respectively, where they more effectively serve as essential background material for the survey chapters in Parts Three and Four. The remaining material on body organization in Chapter 6 was rewritten to be more comparative. Chapter 9 (Digestion and Nutrition) was also largely rewritten and reorganized to provide a much more comparative focus. Several sections in Chapter 8 (Homeostasis) and Chapter 10 (Nervous Coordination) were revised and reillustrated. Figures 8-5 through 8-8 are examples of how new, informative illustrations were designed to complement the text.

Several changes were made in Chapter 13 (Reproduction and Development) to provide a better coverage and at the same time to tighten the writing. Descriptions of cleavage patterns and early embryonic development, formerly in Chapter 6, were integrated into the unit on the developmental process. The description of fertilization was updated with a more accurate explanation of how polyspermy is blocked. Also rewritten in this chapter were the sections on parthenogenesis and the essay “What good is sex?” A new section was added on reproductive patterns, describing different breeding patterns and cycles, and adaptations for care and nourishment of the embryo.

Parts Three and Four present the evolutionary parade of animal diversity and adaptations. This unit begins with a brief history of the science of systematics and explanations of traditional and modern approaches to animal classification. Figure 14-5, a new illustration showing in branching pattern the major advances in architectural themes of animals, will be helpful in introducing the student to the diversity chapters that follow.

The remaining chapters in Part Three cover the panorama of the invertebrate animals. Each chapter received detailed attention, with updating and rewriting as needed. Numerous new figures have been added or replace old figures. Chapter 17 (Radiate Animals) and Chapter 18 (Acoelomate Animals) were extensively reorganized. The rather detailed treatments of structure and function of hydra and planaria were generalized to embrace all cnidarians and platyhelminths in the respective chapters, with the specific discussions of hydra and planaria being abbreviated accordingly. A short paragraph and an illustration of the phylum Loricifera were added to Chapter 19.

The vertebrates are the theme of Part Four. Much of Chapter 25 (Chordates: Vertebrate Beginnings) was rewritten. The remaining vertebrate chapters received minor updates and clarifications, but as a whole not substantially changed. The classification of the mammals (Chapter 30) was abbreviated and its position moved forward in the chapter to parallel the placement of classifications in the other diversity chapters.

## TEACHING AND LEARNING AIDS

### Vocabulary Development

Key words are boldfaced and the derivations of generic names of animals are given where they first appear in the text. In addition, the derivation of many technical and zoological terms are provided in the text; in this way students gradually become familiarized with the more common roots that comprise many technical terms. An extensive glossary of more than 1000 terms provides pronunciation, derivation, and definition of each term.



## Chapter Prologues

A new and distinctive feature with this edition is an opening prologue set off in a panel at the beginning of each chapter. The essays embrace a variety of themes and facts that relate in each instance to the subject of the chapter. Some present biological, particularly evolutionary, principles; others (especially those in the survey sections) illuminate distinguishing characteristics of the group treated in the chapter. Each is intended to present an important concept drawn from the chapter in an interesting manner that will facilitate learning by students, as well as engage their interest and pique their curiosity.

## Marginal Notes

Marginal notes, which appear throughout the book, augment the text material and offer interesting sidelights without interrupting the narrative. We prepared many new marginal notes for this edition and revised many of the existing notes.

## For Review

Each chapter ends with a concise summary, a list of review questions, and annotated selected references. The review questions enable the student to self-test his or her retention and understanding of the more important chapter material.

## Art Program

The appearance and usefulness of this edition has been further enhanced with many new original drawings, all of them full color paintings, by William C. Ober. Bill Ober's artistic skills, knowledge of biology, and experience gained from an earlier career as a practicing physician have enriched this text through all its editions. Bill has been ably assisted for this edition by Clair Garrison.

## SUPPLEMENTS

### Instructor's Manual

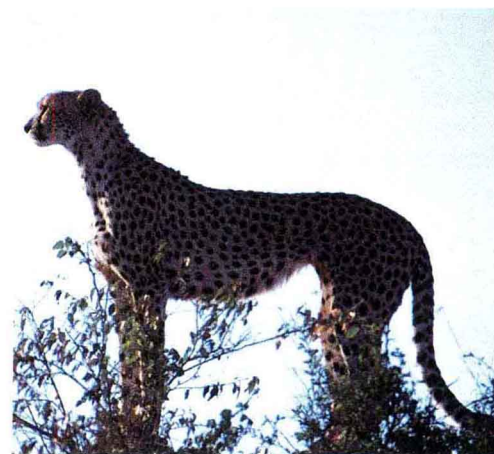
The Instructor's Manual for this edition has been broadly revised and expanded. In addition to test questions, we have prepared a chapter outline, a commentary and lesson plan, and a listing of source materials for each chapter of the text. We trust this will be of particular value for first-time users of the text, but we think experienced teachers will also find much of value, particularly in the commentary and source material sections.

### Laboratory Manual

The laboratory manual by Hickman and Hickman, *Laboratory Studies in Integrated Zoology*, now in its seventh edition, has been extensively rewritten and reillustrated. Although it was written for a year-long course in zoology, it can be adapted conveniently for semester or term courses by judicious selection of exercises. The large wall chart, "Chief taxonomic subdivisions and organ systems of animals," is especially appreciated by students.

## ACKNOWLEDGMENTS

We wish to thank the zoologists engaged by Mosby to review the fourth edition of this text, and who in doing so suggested countless improvements that guided our approach to this revision. We are especially indebted to Peter Dalby, Clarion University, whose detailed line-by-line review of the entire text, combined with an extensive knowledge of zoology, transcended the usual expectations for a reviewer. We thank Kenneth L. Goodhue-McWilliams, California State University, Fullerton, who has generously and warmly shared his perceptive teaching



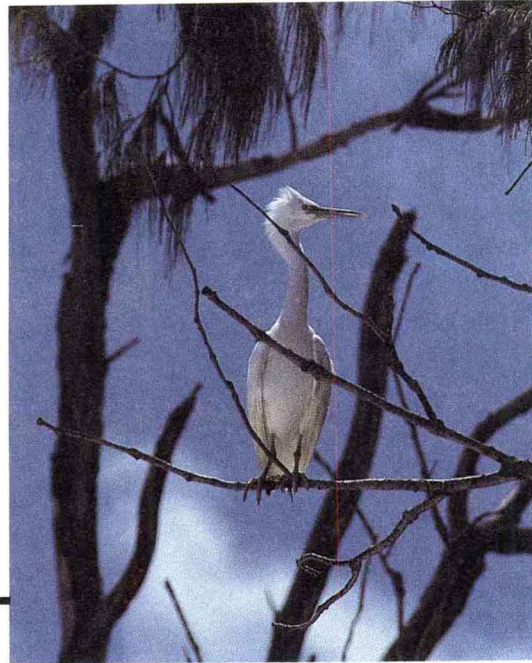


philosophy with us and encouraged us in moving toward the elusive “holistic” text. It is doubtful that we have fully realized his vision for this revision, but his suggestions will be beneficial for years to come. Others to whom we owe special thanks for their insights are DuWayne C. Englert, Southern Illinois University at Carbondale; Standley E. Lewis, St. Cloud State University; Grover C. Miller, North Carolina State University; Lee F. Braithwaite, Brigham Young University; Jeffrey Pommerville, Texas A&M University. We have gained immeasurably from their insights. Our good friend Dean Foster, who has encouraged us with previous editions, read the new chapter prologues and applied his wit and vision to their improvement.

We feel fortunate to have had the continued support of the conscientious staff of Times Mirror/Mosby in the preparation of this fifth edition. We especially thank our editor David Brake, developmental editor Kathleen Scogna, production editor Teresa Breckwoldt, project manager Kathleen Teal, and manuscript editor Alice Fugate. Design and production were directed by Elizabeth Fett and Jean Genz respectively.

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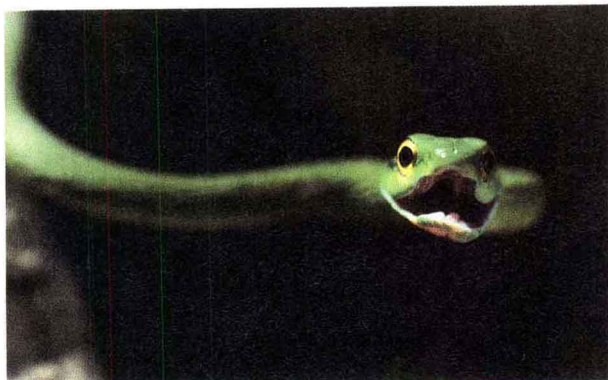
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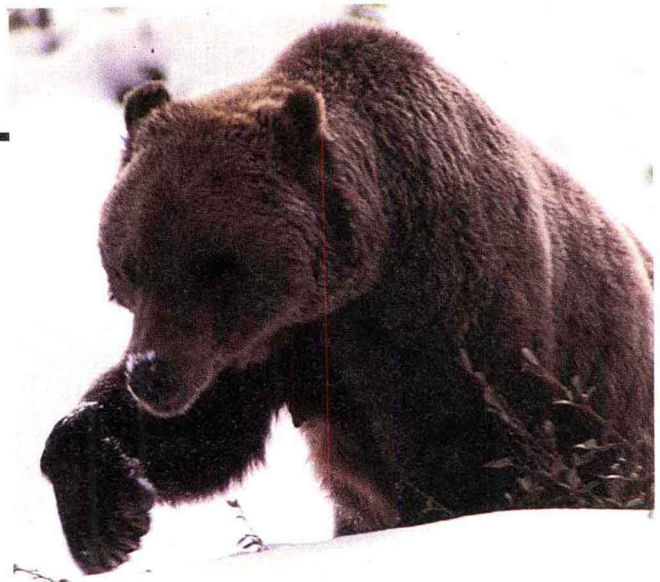
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## Glossary

PART ONE

# Evolution of Animal Life

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LIFE General Considerations, Basic Molecules, and Origins

CHAPTER 2

THE CELL AS THE UNIT OF LIFE

CHAPTER 3

GENETIC BASIS OF EVOLUTION

CHAPTER 4

EVOLUTION OF ANIMAL DIVERSITY

CHAPTER 5

THE EARTH'S ENVIRONMENT



## **T**HAT MYSTERY OF MYSTERIES . . .

Cosmologists endeavor excitedly to understand the origins of the universe in toto and our own little solar system in particular. With backgrounds variously in physics, chemistry, astronomy, and mathematics, these scientists agree that the universe, including the planet Earth, is about 4.5 billion years old. Difficult as the question of cosmic origin is, more challenging still is the issue of the origin of life itself. Most intriguing of recent findings is the consistent picture of very early life on earth as revealed by the fossil record. The oldest fossils yet discovered are filamentous and sheath-enclosed colonial microorganisms from Western Australia that have been firmly dated radioactively at 3.3 to 3.5 billion years old. These are the earliest known life forms, among the first so far as we know to have closed themselves off from the rest of the universe as living, self-reproducing units. Responding then to the forces of natural selection, protocells such as these began to evolve, eventually yielding the web of life on earth today. Throughout time, life and environment have evolved together, each deeply marking the other. The primitive earth, with its reducing atmosphere of ammonia, methane, and water, was superbly fit for the prebiotic synthesis that led to life's beginnings. Yet, it was totally unsuited, indeed lethal, for the kinds of organisms that inhabit the earth today, just as early forms of life could not survive in our present environment.

On such matters did Charles Darwin ponder, that "mystery of mysteries" as he called it, the origins of life and species. It is a journey through time which, little by little, comes to light; the history of life forms that have been, and are being, evolved on this earth.■





# Life

## *General Considerations, Basic Molecules, and Origins*



zoology (Gr. *zōon*, animal, + *logos*, discourse on, study of) is the scientific study of animals. It is commonly considered a subdivision of an even broader science, biology (Gr. *bios*, life, + *logos*, discourse on, study of), the study of all life. The panorama of animal life, how animals function, live, reproduce, and interact with their environment, is exciting, fascinating, and awe inspiring. A complete understanding of all phenomena included in zoology is beyond the ability of any single person, perhaps of all humanity, but the satisfaction of knowing as much as possible is worth the effort. In the chapters to follow, we hope to give you an introduction to this science and to share our excitement in the pursuit of it.

Why study zoology? One of the best reasons is curiosity: curiosity about animals, how they function, and how they relate to one another and to their environment. Understanding why things happen or how they have come to be as they are is satisfying to us. Study of zoology helps not only to understand animals in general, it helps us to understand ourselves, the kind of animals we call humans. Every educated person should have at least a modest grasp of human function to live better and more happily in the world. Certainly, a study of zoology helps us to understand current issues related to such phenomena as environmental destruction and pollution, extinction of species, genetic engineering, in vitro fertilization, the hazards of radiation, and many others. These are, of course, reasons why any person should have some knowledge of zoology, but some people want to study certain aspects in depth and contribute in a tangible way to human knowledge and to the solution of problems in the world. Many students take courses in zoology to help them prepare for a medical, veterinary, or other health-care career, either in clinical practice or as researchers on diseases of humans or other animals.

Some students may wish to become professional zoologists. Because no one person can be expert in all of zoology, zoologists usually specialize in one area and apply their research efforts to a narrow subspecialty within that area. Specialties in zoology can be classified in various ways according to the animal group studied. There are entomologists (who study insects), ornithologists (birds), mammalogists (mammals), ichthyologists (fishes), herpetologists



(amphibians and reptiles), protozoologists (protozoa), acarologists (ticks and mites), arachnologists (spiders), malacologists (molluscs), and many others. But even these are broad groupings; an ichthyologist, for example, would not attempt to assimilate everything about all fishes but would specialize in one aspect of certain types—perhaps classification, behavior, or the biology of their populations. Specialties are also classified along functional lines, irrespective of the organisms studied. For example, a physiologist studies the life processes of organisms, an immunologist studies the immune system and its mechanisms, and a pathologist studies diseases and how the organism responds to them. Other specialties focus on levels of organization: molecular biologists concentrate on the molecular level, population biologists study population regulation and interaction, and an ecosystem ecologist might study all interactions of all the populations in an ecosystem and their relationships with nonliving components.

### ■ The Scientific Study of Animals

On March 19, 1981, the governor of Arkansas signed into law the Balanced Treatment for Creation-Science and Evolution-Science Act (Act 590 of 1981). A historic lawsuit was tried in December 1981 in the court of Judge William R. Overton, U.S. District Court, Eastern District of Arkansas. Plaintiffs included religious leaders and groups of several denominations. They contended that the law was a violation of the First Amendment of the U.S. Constitution, which prohibits “establishment of religion” by the government. On January 5, 1982, Judge Overton permanently enjoined the State of Arkansas from enforcing Act 590.

A basic understanding of zoology requires an understanding of what science is, what it is not, and how knowledge is gained by scientists. It is interesting that a succinct definition of science was rendered in a court of law. On the basis of testimony in the lawsuit, Judge William R. Overton stated the following essential characteristics of science:

1. *It is guided by natural law.* The pursuit of scientific knowledge must be guided by the physical and chemical laws that govern the state of existence and interactions of atoms, subatomic particles, molecules, and so on.

2. *It has to be explanatory by reference to natural law.* Scientific knowledge must explain what is observed by reference to natural law without requiring the intervention of any supernatural being or force. One may believe, as many scientists do, that the universe was brought into existence by the action of a supernatural being, but such a belief is neither within the realm of science nor contradictory to the tenets of science.

3. *It is testable against the empirical world.* We must be able to observe events in the real world, directly or indirectly, for them to have scientific value, and testing of hypotheses and theories must be accessible to our senses or to instruments that can measure the events.

4. *Its conclusions are tentative, that is, are not necessarily the final word.* If we draw a conclusion relative to some event, the conclusion is always subject to further verification. We must always be ready to discard or modify our conclusion if it is inconsistent with further observations.

5. *It is falsifiable.* If our conclusion is not compatible with further evidence, then that evidence has shown that the conclusion is false. As Judge Overton stated, “While anybody is free to approach a scientific inquiry in any fashion they choose, they cannot properly describe the methodology used as scientific, if they start with a conclusion and refuse to change it regardless of the evidence developed during the course of the investigation.”

### SCIENTIFIC METHOD

The manner in which a scientist seeks to gain new knowledge or explain natural phenomena is known as the scientific method. It has sometimes been described as ordinary common sense raised to a higher level and applied systematically. The first step is **observation**. The scientist observes a series of events, often indirectly by means of instruments. Frequently, the events are “observed” by reading descriptions of the observations made by other scientists as recorded in the scientific literature. By use of instruments or literature, the scientist may observe

**Induction** in logic is the process of reasoning from the part to the whole, that is, generalizing from particular observations to apply a conclusion more widely. **Deduction** is reasoning from the general to the particular, that is, from given premises to their necessary conclusion.



otherwise inaccessible events, such as those too small to be seen or those that may have taken place many years previously (Figure 1-1). After considering the observations, the scientist seeks to generalize about them, that is, to make a statement of explanation about the observations, such as their cause, mechanism, and relationship to each other. This is called **inductive reasoning**, which is simply the mental process that allows us to form statements about information we perceive. The statement becomes the **hypothesis**. To have any scientific value, the hypothesis must then be tested. On the basis of the hypothesis, the scientist must deduce its consequences (**deductive reasoning**) to make a **prediction** about future observations. The scientist must say, "If my hypothesis is a valid explanation of past observations, then future observations ought to have certain characteristics." If the observations do have such characteristics, they constitute evidence in favor of the hypothesis and the hypothesis gains strength as an explanation of the events. In experimental science the "future observations" are in the form of experiments. An **experiment** is a manipulative process by which a prediction made on the basis of the hypothesis can be tested. A certain condition or manipulation is applied to an entity (such as a plant, an animal, a container of a substance, or a body of water), and the results are observed. The information acquired (commonly called **data**, singular **datum**) is critically examined, usually by analyzing the data via a branch of mathematics known as statistics. If the data are as predicted, the hypothesis is supported (not proved), but if the data are otherwise, the hypothesis is invalidated. Thus the data are evidence for or against the hypothesis. The condition or manipulation that has been applied and is being tested is referred to as the **experimental variable**. To have confidence that the experimental variable is responsible for the effect observed, another entity just like the first one must be subjected to all the conditions that prevailed during the experiment *except* the experimental variable. This part of the experiment is called the **control**. The difference observed between the experimental subject and the control is thus the effect of the experimental variable. In practice an experiment is almost never performed on a single entity, such as an individual plant or animal, but on a group of individuals; therefore there are an experimental group and a control group. Furthermore, the experiment is usually repeated a number of times. The more data obtained, the more confidence can be placed in the conclusion about the hypothesis.

We should emphasize that the inductive framing of a good hypothesis is a creative process and requires skill and talent. Hailman (1977) stated that "induction is as mysterious as the creation of a great painting or symphony, and like artists and composers, scientists differ in their creative abilities." Admiring colleagues may say of a scientist that the person "asks good questions."

If a hypothesis becomes supported by a great deal of data, and particularly if it is very powerful (that is, explains a wide variety of related phenomena), the hypothesis may attain the status of a **theory**. The student should understand that the meaning of the word "theory," when used by scientists, is not "speculation" as it is in ordinary English usage. The failure to make this distinction has been prominent in the creationism versus evolution controversy (Figure 1-2). The creationists have spoken of evolution as "only a theory," as if it were little better than a guess. In fact, the theory of evolution is supported by such massive evidence that most biologists view repudiation of evolution as tantamount to repudiation of reality. Nonetheless, evolution, along with other theories in science, has not been *proved* in a mathematical sense but is testable, tentative, and falsifiable. It has been tested for more than 120 years, and to date there is no scientific evidence that it is false; indeed, organic evolution is accepted as the cornerstone of biology. On the other hand, although much has been learned about the *mechanisms* of evolution, they continue to be explored and clarified.

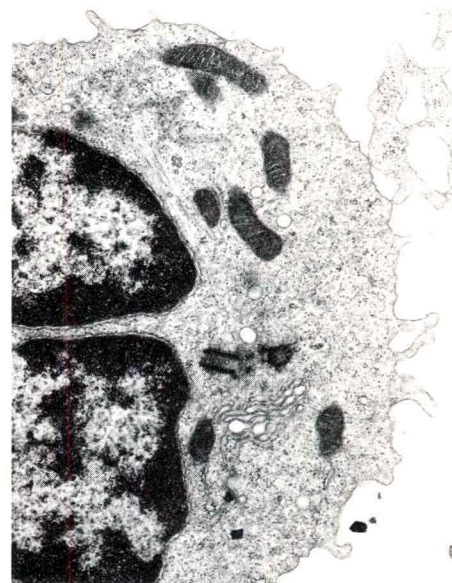


FIGURE 1-1

Scientific instruments are extensions of the scientist's senses. The electron microscope allows us to explore the structure of cells visually. This is a human white blood cell magnified 14,500 times.

Electron micrograph by K.G. Murti/Visuals Unlimited.

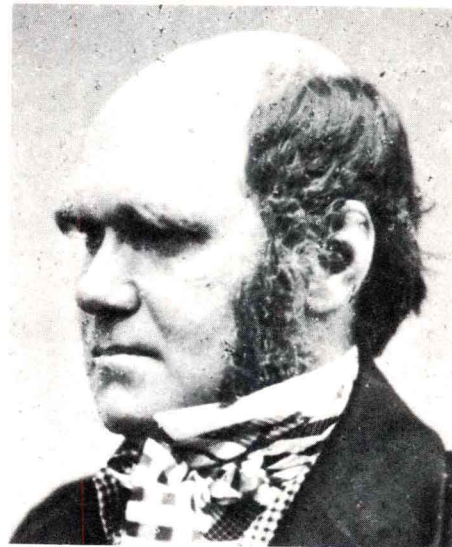


FIGURE 1-2

Modern evolutionary theory is strongly identified with Charles Robert Darwin who, with Alfred Russel Wallace, provided the first credible explanation of evolution—natural selection. This photograph of Darwin was taken in 1854 when he was 45 years old.

Courtesy American Museum of Natural History.



## ■ Some Basic Chemistry

Within recent years, it has been accepted as a first principle of biology that living systems and their constituents obey physical and chemical laws. Within the cells of any organism, the living substance is composed of a multitude of nonliving constituents: proteins, nucleic acids, fats, carbohydrates, waste metabolites, crystalline aggregates, pigments, and many others. Physical and chemical interactions of such substances account for the many processes essential to life, including digestion and absorption of nutrients, derivation of energy, removal of waste, communication of cells with each other, conduction of nerve impulses, and transmission of genetic information from one generation to the next. Because these phenomena will be discussed in later pages, we must present some basic information on chemistry and biochemistry here.

### ELEMENTS AND ATOMS

All matter is composed of **elements**, which are substances that cannot be subdivided further by ordinary chemical reactions. Only 92 elements occur naturally. The elements are designated by one or two letters derived from their Latin or English names (Table 1-1). The elements are composed of discrete units called **atoms**, which are the smallest components into which an element can be subdivided by normal chemical means.

Table 1-1 Some of the most important elements in living organisms

Element	Symbol	Atomic number	Approximate atomic weight
Carbon	C	6	12
Oxygen	O	8	16
Hydrogen	H	1	1
Nitrogen	N	7	14
Phosphorus	P	15	31
Sodium	Na	11	23
Sulfur	S	16	32
Chlorine	Cl	17	35
Potassium	K	19	39
Calcium	Ca	20	40
Iron	Fe	26	56
Iodine	I	53	127

### Subatomic particles

Each atom is composed of subatomic particles, of which there are three with which we need concern ourselves: protons, neutrons, and electrons. Every atom consists of a positively charged nucleus surrounded by a negatively charged system of electrons (Figures 1-3 and 1-4). The nucleus, containing most of the atom's mass, is made up of protons and neutrons clustered together in a very