INTEGRATED PRINCIPLES OF ZOOLOGY

FIFTH EDITION

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WITH 922 ILLUSTRATIONS

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PREFACE

With the broadening of the authorship in this edition, it seems appropriate to reassure past users that the fundamental aim of the book remains unchanged. Our aim is to provide students of zoology with an acquaintance and appreciation of animals and the nature of animal life as it is presently understood. Zoology is a discipline that deals with an animal in all its aspects. Considered purely as a living organism, an animal is a self-perpetuating, self-regulating physicochemical system that is in continuous adjustment with its environment. This admittedly colorless description of an animal nevertheless serves to emphasize that understanding what an animal is, what it does, and where it comes from requires the fusion of numerous disciplines of study ranging from the burgeoning field of molecular biology to evolution and population biology. The zoologist must be concerned with an animal's morphology, its physiology, its behavior, its environmental relationships, its development, and its evolutionary history.

The amount of information that has been accumulated in any one of these areas is enormous; combined, it is beyond the comprehension of any one person to grasp. Furthermore, many aspects of life itself remain unsolved. Fortunately, despite their complexity and diversity, animals share a basic organization of form and function, and all have arrived where they are today through the same evolutionary process. Consequently, it is possible to order and integrate our present knowledge about animals into a logically developed presentation, as we have attempted to do in this undergraduate textbook of zoology.

A text such as this must be selective in its treatment. We have tried to balance our description of long-established principles of zoology with the more recent adventures in scientific exploration that have exploited the techniques of biochemistry, developmental biology, molecular biology, and submicroscopic histology. Nevertheless this text will undoubtedly reflect the interests and prejudices of not only the senior author, who has devoted a lifetime to studying and teaching zoology, but the junior authors, one an active participant in current physiologic research and the other with a primary interest in the invertebrates.

While retaining the aims and basic organization of previous editions, we have made significant changes in many sections of the book. The discussion of atomic structure and bonding has been rewritten. Chapter 2 also contains an expanded consideration of protein and nucleic acid structure and new illustrations have been added. The descriptions of membrane structure and function in Chapters 3 and 4 have been greatly expanded and other important changes have been made in discussions of cell division, membrane transport processes, and enzyme function. The section on cellular metabolism has been completely rewritten and reillustrated.

The invertebrate chapters have been revised to include a broader consideration of the diversity of life within each phylum and less anatomy of representative types, which are adequately covered in the laboratory manual. Many illustrations have been replaced and many fine photographs of living invertebrates in their native habitats have been added.

The six chapters on the phylum Chordata have been completely rewritten and reillustrated to incorporate new material, improve clarity, and reorder emphasis. Chapter 21 retains the morphologic descriptions of the ammocoete larva and amphioxus that many teachers have found useful, but the section on chordate ancestry and evolution has been thoroughly recast to emphasize theories of early vertebrate ancestry and the problems surrounding attempts of biologists to reconstruct lines of vertebrate descent. Considerations of the evolution of each vertebrate class have been shifted to the specific vertebrate chapters, where we believe they will be more helpful to the student. The chapter on fishes has been considerably expanded and completely reillustrated, and we have adopted a more modern classification for the fishes. As with the invertebrate chapters, emphasis in all the vertebrate chapters has been directed to adaptations, natural history, evolution, and diversity. Morphologic description has been reduced in keeping with our desire to avoid unnecessary overlap with the laboratory manual. Numerous new photographs have been carefully selected to illustrate the vertebrates and their adaptations.

Part Three, on the physiology of animals, was rewritten to include the rich harvest of recent discoveries in this area. Many old illustrations were replaced with new drawings and several scanning electron micrographs were generously contributed by biologists who are acknowledged in the legends. We have also rewritten the chapter on development to focus on gene expression and other recent discoveries that have so vastly enriched our current understanding of the developmental process.

Chapter 39 has been expanded in keeping with the current growth of interest in problems of the ecosystem. As in former editions, the final chapter is devoted to meaningful developments in the field of zoology. The historic background of fundamental discoveries is too often neglected in presenting zoologic information to students, yet most teachers realize that every important discovery rests upon foundations assembled by others.

The lists of references at the ends of the chapters have been reviewed and updated to make the selections as authoritative and pertinent as possible. We have for the first time separately listed a selection of readings from the popular and highly accessible *Scientific American* magazine.

Beginning with the first edition, many professional zoologists have read parts of the manuscript and offered useful suggestions and criticisms. In addition to those gratefully acknowledged for their assistance in previous editions we wish to thank Dr. J. Ralph Nursall and Dr. Joseph Nelson, of the University of Alberta, and Dr. Thomas G. Nye and Dr. Edgar W. Spencer, of Washington and Lee University, for reading portions of this manuscript and contributing valuable advice.

William C. Ober of Charlottesville, Virginia, prepared most of the many new drawings that appear in this edition. He has contributed not only unusual artistic skill but also many valuable suggestions for improving the instructive value of the illustrations. Other new drawings were executed by Sheila Ford, Provo, Utah; Barbara Hyams, Montreal, Quebec; and Katherine Payne, Alexandria, Virginia. We are indebted to many individuals who provided photographs for this edition. Their names are indicated in the pertinent legends. We wish especially to thank Bo Tallmark, of Uppsala University, Sweden; Tomas Lundälv, of the Kristinebergs Zoological Station, Sweden; and Leonard L. Rue, III, of Blairstown, New Jersey, all of whom spent many hours assisting in photograph selections with the second author. Many scanning electron micrographs were generously contributed by Dr. P. P. C. Graziadei, of Florida State University; and Professor C. G. Hampson, of the University of Alberta, provided several fine bird and mammal photographs that appear in Chapters 25 and 26. We are grateful to them all.

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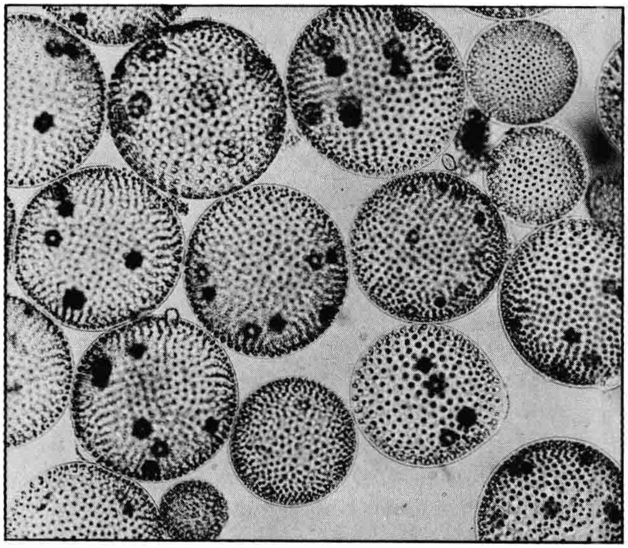
CONTENTS

PART ONE

INTRODUCTION TO THE LIVING ANIMAL

■ In these five chapters, we discuss the basic nature of life as we understand it today. So far as can be determined, the same materials and physical and chemical laws of the nonliving world also apply to the living. The essential difference appears to lie in the organization of the elementary materials of the nonliving into the highly specific architecture of the living. In its simplest form, life is associated with a heterogeneous substance constructed of organic macromolecules. From this substance has evolved an organizational hierarchy of cells, tissues, organs, organisms, and, finally, the vastly complex community of life, the ecosystem. The living animal's activity, growth, reproduction, and use of its environment requires a still further organization of energy processes beyond that encountered in the strictly nonliving world.



The colonial Volvox—*an organization level between the unicellular and the multicellular.*

CHAPTER 1

LIFE: GENERAL CONSIDERATIONS AND BIOLOGIC PRINCIPLES

WHAT IS LIFE?*

The concept that living things on this planet came from the nonliving is rather firmly established in the minds of biologists, even though it is highly speculative regarding how this phenomenon occurred. In recent years many scientists have advanced theories to explain the origin of life. Some of these theories have experimental evidence to back them up to some degree. Although it is difficult to define life, the difference between the living and the nonliving is becoming clearer as scientists understand more about the basic substance of life. Both the living and the nonliving share the same kind of chemical elements and both follow the law of the conservation of energy. The essential difference between the two appears to be organization. The living organism has combined atoms and molecules into patterns that have no counterparts in the nonliving. Examples of these patterns are the complex macromolecules of proteins and nucleic acids that give rise to the properties of life. Such combinations have dynamic systems of coordinated chemical or physical functions or activities that, taken as a whole, distinguish the living from the nonliving. The living differ from the nonliving not so much in qualities as in the way its substance is organized into unique patterns of position and shape. The organism is a system of interwoven and overlapping hierarchies of organization.

Almost any single criterion one may take of the living has its counterpart in the nonliving. Most characteristics of life are found to some extent in the inanimate world, which may indicate the close relationship of the two. Only animate things, however, have combined these properties into unique functional and structural patterns. One of the most fundamental properties of living matter is perhaps its uniqueness in reproducing itself, but there are other im-

*Refer to p. 17, Principle 2.

portant aspects that deserve attention. Life illustrates a unique integrity under the impact of the environment so that it can adjust itself by its own energy.

Another important difference that the living possess is the intimate relationship between life and its environment. The evolutionary history of the organism has placed it specifically in certain environments and has determined its physical properties and different capabilities. Life and the environment are part and parcel of each other, and its innate behavior patterns and physiologic capabilities determine how well it gets along and adjusts itself to changing environmental conditions. This relationship between organism and environment is well shown by the behavior adjustments of correlative rhythms it must make to fluctuating surroundings. In other words, the interaction between the living and the nonliving has determined the character of life and to a certain extent the character of the earth planet on which we live. At all times in its daily living the organism is inseparable from its environment.

NATURE OF MATTER

Matter is the substance that comprises entities perceptible to the senses. The chief properties of matter are gravitation and inertia. Mass, which all material bodies have, is a measure of inertia. Matter and energy make up the universe, and these two components are interconvertible according to Einstein's theory of relativity, which is expressed in the equation Energy = mc^2, where m equals the mass and c equals the speed of light. This equation represents the theoretic basis for converting matter to energy. As we commonly understand matter and energy, they are separate. Matter in whatever form it may be (solid, liquid, or gas) occupies space and has weight. Energy has the ability to produce change or motion or the ability to perform work.

Both the living and the nonliving are made up of atoms. As will be pointed out later, living matter is more selective and has fewer kinds of atoms (although the same kinds are also found in the nonliving). An analysis of living matter after death shows no change in its atoms or elements. Living matter varies according to the general type of animal. Terrestrial animals have more nitrogen and sodium but less potassium, silicon, and aluminum than do aquatic forms. Marine organisms have more chloride and more water than do terrestrial organisms.

But the presence or absence of specific elements alone cannot explain the fundamental difference between the living and the nonliving. The chief difference is the arrangement of atoms into huge organic macromolecules that are able to display the basic properties of life.

LEVELS OF COMPLEXITY

Life is made up of a hierarchy of structure and function, ranging all the way from the atom and molecule to the highly developed and complex community, or even to levels of the ecosystem. This concept involves the nonliving as well as the living and is commonly divided into the following levels of organization: atom, molecule, organelle, cell, tissue, organ, organism, community, and ecosystem. Starting with the atom, it is seen that each level furnishes the building stones for the units of the next higher level. Of course, one can start with a lower level than the atom, the elementary particle, of which about 70 have been found. At each level are properties that are more or less unique for that level. Molecules of water have different properties from separate hydrogen and oxygen atoms. The large macromolecules may be considered as the lowest biologic level.

It will be noted that any given level contains all the lower levels as components. All the structural levels up to and including the molecular components are common to both the animate and the inanimate.

Cells are made up of organelles, and since cells are the lowest levels that can be considered alive, it follows that an organism must have at least one cell (unicellular). Organisms other then the unicellular ones are the multicellular organisms (metazoa). A level between the unicellular and the multicellular is the protistan colony, in which the cells are more or less alike. It is thus possible for the organism as a whole to have one or the other of five levels of organization complexity—the unicellular form, the colonial form, the cell-tissue level organism, the tissue-organ level, and the organ-system level.

Levels other than those already mentioned may be distinguished in the grouping of organisms, such as species, genera, families, populations, and communities. This structural hierarchy may represent the evolutional history of matter, both the living and the nonliving. This would indicate that, level by level, matter has become organized progressively to form the hierarchy as we now have it.

It will be noted that each level has fewer units than lower levels. For instance, there are fewer tissues than cells and fewer cells than organelles. Each level also has, in addition to its own complexity, the complexities of all the lower levels. In the shift from one organization level to another, energy is expended, and when a higher level has been attained, energy is necessary to maintain that level. A price in energy is required for the new properties that are acquired by having a higher level and the environmental advantages such a level confers.

This hierarchically organized matter reveals one of the basic aspects of life in that it provides the great concept of the evolution of matter from the nonliving to the living and gives a meaningful interpretation to the whole problem of the origin of life.

COMPARISON OF THE LIVING WITH THE NONLIVING*

One of the characteristics of life is that it is an action-performing system of definite boundary, undergoing a continual interchange of materials with the environment, requiring energy to run the system and matter to repair it whenever needed. This may be called a metabolic criterion, which is actually made up of three vital processes; nutrition, respiration, and synthesis. It is true that some inanimate objects could very well simulate this metabolic criterion. A steady flame, such as that of an oil lamp, has a definite boundary and continually takes up oxygen, and gives off carbon dioxide and water, just as an organism would do. The similarity, however, is superficial, as the student will discover when he studies cellular metabolism and the complex metabolic pathways of enzymatic action. The metabolic criterion is almost nonexistent in suspended animation or in seeds and spores.

The metabolic mechanism by which chemical changes are brought about is made up of teams of enzymes. Although enzymes are biologic catalysts and catalysts exist in the chemical reactions of the nonbiologic world, the enzymes have an entirely different structure, being essentially proteins. Some enzymes have in addition a prosthetic group of a metal or a coenzyme of an organic compound. Indeed, all living matter may be considered an organized system of enzymes dispersed in an aqueous solution.

*Refer to p. 20, Principle 19.

Metabolism has two types—anabolism and catabolism. Anabolism is a chemical process in which simpler substances are built up into more complex ones for storage and growth and also to produce new cellular substances. On the other hand, catabolism is the breaking down of complex substances for releasing energy and the natural wear and tear on bodily structures by living processes. These two types are so woven together and so interdependent that it is difficult to separate them in the living process. As the student will see later, the body parts are in a state of flux by which interconversion of the basic substances is continuously occurring. Catabolism breaks down complex compounds for the release of energy that is needed in every aspect of life. Living matter is never the same at any two instances.

Another fundamental difference between the living and the nonliving is the specific organization of the former. In general, the organism has an upper size limit and a characteristic shape, whereas such factors are variable among nonliving substances. More basic still is the specialization of parts in the organism as expressed in the hierarchy described above. Organization, as we have seen, is one of the key criteria, and this involves different parts, each with its special function. Cells, tissues, and organs, so characteristic of life, have no counterparts in the nonliving world. Furthermore, a living system is a highly permanent form of matter, and its basic pattern was laid down perhaps in the first cells.

All living matter has certain basic properties of irritability, conductivity, movement, excretion, secretion, absorption, respiration, reproduction, and growth. As will be explained later, these functions form the basis for the development of the specialized tissues that are characteristic of all organisms. Each of these tissues is made up of the basic structures of cells, intercellular substances, and body fluids of various kinds that bathe the cells. Of all these properties, that of reproduction must be considered the most fundamental property distinguishing a living thing. This property of reproduction and its mutant types, or variables under the influence of natural selection, have made possible the course of evolution by which present living forms are found as they are.

WHERE IS LIFE FOUND?

At present there is no convincing evidence that life exists elsewhere than on our planet Earth. Nor is there evidence that the physical conditions, which made life possible on this planet, are also duplicated elsewhere in the universe. But the immensity of the universe with its countless billions of stars and other bodies is beyond man's comprehension, and that similar conditions might be found elsewhere is within the realm of possibility. Matter is found within the universe as gas clouds, dust, rocky bodies, and stars. Stars are gathered together to form galaxies. According to astronomic calculations, stars are vast reservoirs where there are conversions of matter and energy. Within stars there has occurred the evolution of the elements with which we are acquainted here on our planet. Stars have life histories. Some are young and others old. Their properties change with time in their life history. Some stars die and return their matter and energy to interstellar space; others are born, probably from the same substances released by the disintegration of the older stars. Cosmic evolution is as real as is organic evolution on a smaller scale. But it is impossible to think of life within a star because of temperature and other conditions. If life is present elsewhere in the universe, it must be on satellites of stars. Only there would one find temperature and density conditions that might support life.

The old theory of the origin of life on earth from spores or similar bodies carried to this planet is not worthy of consideration. Such bodies could not withstand cosmic radiation, and it is simply "passing the buck" as far as explaining the origin of living matter is concerned.

It is possible that life may exist under different conditions from those under which it does on earth. All such matters are highly speculative and are not backed up by a shred of evidence. In recent years some study has been made of certain meteorites that contain a variety of hydrocarbons. Carbonaceous meteorites are not common, and the view that they may carry evidence of life from extraterrestrial sources has aroused some interest. Investigation has shown that organic material (hydrocarbons, fatty and aromatic acids, water, etc.) is found as microstructures embedded in the meteorite matrix. It is not known with certainty just where these meteorites originated—whether they are of lunar, comet, or solar nebula origin. At present it is impossible to determine whether such substances are abiologic or of extraterrestrial biologic origin.

BIOCHEMICAL BASIS OF LIFE*

Enough has been discussed in previous topics to indicate that living matter is made up of molecules that have biochemical roles. Although this aspect of life is discussed more fully later, it will suffice here to point out the significance of the biochemical background in a résumé of the general features of life.

Animals have only a fractional part of the chemical atoms found in nature. Hydrogen, oxygen, nitrogen, and carbon make up 98% to 99% of living substance (protoplasm). Some 25 to 30 other atoms are also found, many of which have been assigned restricted roles in the life process. But others, such as calcium, iron, and sodium, have wider and more general roles, yet are far less common than the "big four." The predominant elements of animals—C, N, O, H, P, and S—make up most of the molecules of life. The importance of life's constituents will be evaluated in a later section. The smaller life molecules are amino acids, sugars, fatty acids, the purine and pyrimidine bases, and the nucleotides. These smaller molecules are also constituents of the larger macromolecules of proteins, nucleic acids, glycogen, starch, and fats. The basic building blocks of all the macromolecules contain hydrogen, carbon, and oxygen. Some also have phosphorus, nitrogen, and sulfur.

Diversity in biochemical process is found especially in the metabolic functions and pathways of biosynthesis and other functions. This diversity is particularly striking in the different macromolecules used for the transportation of oxygen. Some organisms use copper-containing proteins and others iron-containing proteins, yet the different molecules perform similar tasks. Anaerobic breakdown of glucose may yield alcohol (yeast) or lactic acid (muscular contraction). Diversity is also shown in the ability to synthesize the various amino acids. Man cannot synthesize certain amino acids (essential amino acids). Rats require even more essential amino acids. Animals also vary in the ability to synthesize other molecules necessary for life.

Even though there is diversity, there is also unity or repetitious performance in metabolic patterns. The genetic code for DNA and RNA appears to be universal in all organisms. Proteins, nucleic acids, and amino acids are practically the same throughout the animal kingdom and the great energy package, ATP, is common to all.

*Refer to p. 17, Principle 2.

ENERGY RELATIONS

The reactions of living systems to make energy available represent a large part of their total activities. We have already mentioned the two fundamental components of the universe, energy and matter, and have indicated that under certain conditions they are interconvertible. There may be diversity in the different directions of their metabolisms, but all living systems require energy. Plants (autotrophic) use the energy from sunlight to construct organic substances such as carbohydrates, proteins, fats, and nucleic acids from carbon dioxide, water, nitrogen, and other compounds. Certain bacteria (chemosynthetic autotrophs) use reducible inorganic substances such as iron or sulfur as energy sources. Multicellular animals are heterotrophic and must depend on preformed organic food compounds for their energy. Some lower forms, such as the protozoa, some bacteria, and algae, must also depend on preformed compounds for energy purposes.

Even though photosynthesis is lacking in animals, their biochemical reactions are similar to those in plants. As will be seen under **cellular metabolism,** each biochemical reaction involves energy transfer and conversion, although not all reactions produce or utilize energy-rich substances. As far as animals are concerned, there are many energy transformations in cells, such as chemical to electrical energy in nervous processes, light to electrical in the retina of the eye, chemical to osmotic in the kidney and cell membranes, chemical to radiant in luminescence, sound to electrical in the ear, and chemical to mechanical in muscles and cilia.

Two kinds of energy are recognized by physicists: potential energy, as stored energy or energy of position, and kinetic, or the energy of motion. A familiar example of the two kinds is illustrated by a stone on an elevation where it has potential energy while at rest and kinetic energy when it rolls down to a lower level. Energy is stored as potential energy in the bonds that hold the atoms together in molecules of food. This potential energy can become kinetic energy when the animal transforms this food in its biochemical activities.

Thermodynamics, which is concerned with energy and its transformation, has two basic laws: the law of the conservation of energy, according to which energy can be transformed but not destroyed, and the law of entropy, which states that during any reaction or process there is a decrease in free energy in that some energy is dissipated to the environment as heat and unavailable energy.

The energy relations of the organism give a basic understanding of the true nature of an animal or organism. The numerous interacting systems of an animal can be maintained only by the continuous expenditure of energy. The biochemical interactions found in the transformation of the energy of oxidation necessary for physiologic work are complex, and the animal must be viewed as a highly adaptable dynamic system that is in continuous exchange of energy relations with its environment.

PROTOPLASM AS THE LIFE SUBSTANCE*

The substance making up the organism is often termed living matter, or protoplasm. The term "protoplasm" is less used by biologists than it was formerly. Instead of the concept that protoplasm is chiefly a colloid, the intrinsic meaning of the life substance is placed on a physicochemical appraisal of the types of forces and the chemical bonds that give living matter its rigidity and its fluidity. Consequently protoplasm is often now regarded as a vague and nebulous term.

Protoplasm is not homogeneous matter, and no drop of it can be called truly representative of the whole. It is a complex colloidal system, represented by phases of particles of widely varying sizes, physical natures, and chemical constitution. There is little to be learned by superficial examination of protoplasm from any source, and before the electron microscope and the era of molecular biology such descriptions are to a great extent worthless. Its organization, according to our present knowledge is not static but dynamic. It maintains itself by a continuous building up and breaking down of the substances that compose it. Much further investigation will have to be done before a rational evaluation of living matter can be made.

UNDERSTANDING THE NATURE OF LIFE

Much has been learned about the nature of life within the past few decades. How has this understanding come about? To understand living matter and the processes of life is difficult, for the life

*Refer to p. 17, Principle 1.

sciences do not lend themselves as easily to analytical methods as do the physical sciences. Any attempt to understand the nature of life involves a careful study of the processes by which the animal acquires the characteristics of living matter. If one selected an animal at random and attempted to learn all that is known about the basic principles of life from it and others like it, he would find that there would be many gaps in his final understanding. During the past few years the frontier of life sciences has been pushed more and more toward the molecular level. Biochemistry has come into greater prominence. Biophysical methods loom up at every step in analytical interpretation. Biologic investigation requires the methods and techniques from all scientific disciplines. This signifies that no one person has all the skills necessary to master all the analytical procedures required in most biologic investigations, even those of a modest scope.

One of the most outstanding advances made in the life sciences in recent years has been the development of our knowledge of the genetic code, or the manner in which the chromosomal genes carry the information for protein synthesis. By precise analytical methods it has been possible to determine that genetically controlled variants of a protein can be produced by changes in single amino acids. As the student will see in the discussion of the genetic code, an alteration in a tiny subunit of a gene is responsible for a different kind of amino acid. It is thus possible for information to be carried in the nucleotide sequence of the deoxyribonucleic acid (DNA) molecule and to be transformed into the amino acid sequence of a definite protein. The amount of work done by numerous investigators to prove how this process operates has been tremendous and includes many years of work.

THE "NEW BIOLOGY" AND ITS LIMITATIONS

The distinction between the life sciences and physical sciences is rapidly being broken down. No longer is the world of the zoologist set apart from the world of the physical scientist, nor are the phenomena of animal life considered to exist outside the realm of the inanimate.

This change in animal study has been so spectacular and so radical as compared with the classic study of zoology that the new approach has been called the "new biology." This innovation in zoologic study has had a revolutionary impact on methods of study and on the training of zoologists. Many persons who are not zoologists are now active in this field because the disciplines of biochemistry, physical chemistry, and physics are now considered by many to be necessary prerequisites for zoologic study. This has resulted in a tendency to exclude from the training of zoologists anything not directly related to the physical sciences.

Although this trend in zoologic study is pronounced, many zoologists regard it as extreme and altogether inadequate for an effective understanding of the life disciplines. Molecular biology is an important level of study, but there are also many others. The major aim of biology is to understand all aspects of life organization, not merely the molecular structure. The various disciplines of the life sciences cannot be arranged in a hierarchy of importance. One discipline may arouse a greater interest at one time, and much progress may be made in its development, for example, cytology in the last quarter of the last century and genetics and evolution in the first half of the present century; but for true biologic understanding, other disciplines such as taxonomy, ecology, and paleontology must make their contributions.

The true zoologist is interested in the whole organism, both functionally and structurally at all levels of organization. The functions of biologic molecules with which the biochemist is now so concerned can be understood and appreciated only in the light of their relations to the whole organism, its environment, its population structure, and its past history.

The major aim of most competent biologists is to discover facts and to establish biologic generalizations that can be applied to an understanding of the phenomena of life. Most scientific discoveries are not far removed from their practical applications. The rapid advance of biologic investigation and its exciting discoveries have already aroused many enthusiastic biologists to believe that man will soon be able to control his destiny in ways never dreamed of before. The possibility of directing mutations in certain microorganisms by means of specific agents, the genetic alteration or chemical hybridization of bacteria by the processes of transformation and transduction, the wide use of animal tissue cultures (including human) for analysis of genetic constitutions at the cellular level, and the development of techniques for extracting the major substance (DNA) of the gene have all been responsible for the belief that man will be able in the near future to remake or alter his own hereditary constitution. Similar enthusiastic beliefs have been advanced before when a major breakthrough in scientific achievement occurred, but in every case a cooling-off period followed under the impact of a more sober and realistic realization of scientific limitations.

However, certain aspects about the scope and future direction of biology can be predicted with reasonable assurance. Molecular biology will, of course, unfold more information of the inner working of the cell, such as the synthesizing processes of the many complex systems of the cell, under the impact of the decoding mechanisms of genetics. A breakthrough of great significance may be expected in the fields of development, differentiation, and growth of organisms. At the higher levels of community and population ecology, the application of the preceding studies as well as those of other biologic disciplines will no doubt contribute materially to the adaptation of animals (including man) to their physical and biotic environments. Much of man's efforts will have to be expended in correcting or redressing his mistakes in upsetting natural communities. Out of these and other advancements, there are gradually emerging a keener recognition and analysis of man's cultural evolution, a more basic understanding of man as a biologic unit, and an effective motivating sense of his social responsibility.

WHAT IS AN ANIMAL?

The simple dictionary definition of an animal is not satisfactory to a biologist who appraises the living organism from its organization, properties, and historic character. The more we know about an animal the greater the difficulty in defining it. A definition of an animal that would exclude all plants cannot be made within the limits of a short, logical statement. Perhaps we should confine ourselves to defining any living organism and thus avoid debatable grounds that arise when different organic types are considered. For instance, certain basic differences between higher animals and higher plants are apparent and distinctive (Table 1-1), but among the lower forms of both the plant and animal kingdoms the

TABLE 1-1
Chief differences between plants and animals

Plants	Animals
Usually autotrophic or holophytic nutrition; simple minerals from soil and CO_2 from air; energy from sunlight to synthesize complex materials (photosynthesis)	Usually heterotrophic or holozoic nutrition; require complex, synthesized foods from plants or other animals
Usually rigid cell walls containing cellulose	Usually without cell walls; no cellulose
Oxygen as a waste product	Carbon dioxide, ammonia, urea, uric acid, and other simple substances as waste
Usually no movement or restricted movement	Locomotion usually characteristic; body parts with movement
Usually with variable body shape and size	Invariable body form; definite number of body parts
Organs added externally and growth not sharply restricted	Internal organs and restricted growth
Usually restricted response to stimuli	Usually pronounced response to stimuli
Carbohydrates stored as plant starch	Carbohydrates stored as glycogen

members grade imperceptibly into each other. The acellular or single-celled forms of both are now often lumped together under the Protista (Gr. *prōtistos,* first of all), a term proposed long ago by Haeckel. In general, plants are characterized by cellulose cell walls, synthesis of complex organic foodstuffs by photosynthesis (holophytic nutrition), inconstant body form, limited movement, and external organs; and animals are characterized by absence of cellulose cell walls, fairly constant body form, holozoic nutrition (ingestion and digestion of organic matter), mostly internal organs, pronounced movement, and definite irritability.

On the basis of what was stated about the living and the nonliving, we may tentatively define an organism as a **physicochemical system of specific and varying levels of organization patterns, self-regulative, self-perpetuating, and in continuous adjustment with its environment.**

DEFINITION OF ZOOLOGY

Zoology (Gr. *zōon,* animal, + *logos,* discourse) is the branch of the life sciences that deals with the animal organism as contrasted to botany, the science of the plant organism. Both zoology and botany make up the science of biology (Gr. *bios,* life, + *logos,* discourse), or the study of living things. The distinction between animals and plants is mainly one of convention rather than of basic differences. The biologic sciences are empirical; that is, knowledge about them is acquired by observation and experimentation. Theories and hypotheses must be testable and must be verified in a life science, as in any other science. At present a life science may be considered a descriptive science, in contrast to an exact science such as physics, but progress in molecular biology and the effective application of mathematics, biochemistry, biophysics, and other disciplines to biologic problems are providing the life sciences with a more exact status.

At the present time emphasis is placed on the following subdivisions of the life sciences, although much work is also done in related fields:

Genetics and molecular biology
Metabolic transformations
Cellular and subcellular structures and functions
Developmental biology
Function of tissues and organs
Behavior biology
Ecologic and pollution problems
Evolution and population biology

There is much overlapping and interrelation among the various fields of zoologic investigation. For example, cytogenetics represents the close dependence of two branches of study, cytology and genetics, which were formerly considered more or less separately. As specialization increases, branches of study become more restricted in their scope. We thus have protozoology, the study of protozoans; entomology, the study of insects; parasitology, the study of parasites; and many others.

The following are definitions of some of the important areas of zoologic study.

anatomy (Gr. *ana,* up, + *tomē,* cutting) The study of animal structures as revealed by gross dissection.

anatomy, comparative The study of various animal types from the lowest to the highest, with the aim of establishing homologies and the origin and modifications of body structures.

biochemistry (Gr. *bios,* life, + *chēmeia,* alchemy) The study of the chemical makeup of animal tissues.

cytology (Gr. *kytos,* hollow vessel) The study of the minute parts and functions of cells

ecology (Gr. *oikos,* house) The study of animals in relation to their surroundings.

embryology (Gr. *embryon,* embryo) The study of the formation and early development of the organism.

endocrinology (Gr. *endon,* within, + *krinein,* to separate) The science of hormone action in organisms.

entomology (Gr. *entomon,* insect) The study of insects.

genetics (Gr. *genesis,* origin) The study of the laws of inheritance.

helminthology (Gr. *helmins,* worm) The study of worms, with special reference to the parasitic forms.

herpetology (Gr. *herpein,* to creep) The study of reptiles, although the term usually embraces both reptiles and amphibians.

histology (Gr. *histos,* tissue) The study of structure as revealed by the microscope.

ichthyology (Gr. *ichthys,* fish) The study of fishes.

morphology (Gr. *morphē,* form) The study of organic form, with special reference to ideal types and their expression in animals.

ornithology (Gr. *ornis,* bird) The study of birds.

paleontology (Gr. *palaios,* ancient, + *onta,* existing things) The study of past life as revealed by fossils.

parasitology (Gr. *para,* beside, + *sitos,* food) The study of parasitic organisms.

physiology (Gr. *physis,* nature) The study of animal functions.

taxonomy (Gr. *taxis,* organization, + *nomos,* law) The study of the classification of animals.

zoogeography (Gr. *zōon,* animal, + *gē,* earth, + *graphein,* to write) The study of the principles of animal distribution.