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PART 1 UNITY

The earth is populated by millions of different types of living creatures. Each has its own way of living, but all share *the only known kind* of structural and chemical organization that means *being alive.* Whatever their dissimilarities, plants, animals, and other creatures solve their big problems—those of being alive—in much the same way. Investigation into the unifying features of living will emphasize two things: *what* biologists know about life and *how* they have managed to acquire this knowledge.

CHAPTER 1 **BIOLOGY—WHAT IS IT ABOUT?** 3

Biology is the sum of man's knowledge about life—his own life and that of all other creatures. This knowledge consists not only of a collection of facts, but more importantly, of the way these facts are associated and interpreted in general theories. Clues to the study of biology appear in the principal themes introduced in this chapter. An example of a biological investigation follows as a case history of one problem—the cause of mankind's most serious disease, malaria.

CHAPTER 2 **LIFE FROM LIFE** 23

Less than a century ago scientists debated furiously the question of whether life could rise spontaneously from nonliving substances. The far-reaching implications of this biological question are not necessarily the same for life today and life in its most distant past. But they *are* the same for all kinds of living things, as investigation of this biological problem in terms of life today has abundantly illustrated.

CHAPTER 3 **BASIC STRUCTURE** 44

Unifying theories explain isolated facts. Science is at its best when it seeks a new theory to organize an accumulation of poorly understood facts. One of the greatest unifying theories of biology is that all, or nearly all, forms of life have a common basic structure. That this is true is not at all obvious: a fish and a tree really do not seem to resemble one another. Yet both are alike in being composed of cells. Cells were first discovered almost 200 years before their nature was understood well enough to lead to the cell theory.

CHAPTER 4 **BASIC FUNCTIONS** 65

If nearly all forms of life have a common basic structure—cells—do they also have common functions? Does life as a fish have anything in common with life as a tree? This biological question is closely connected with the history of chemistry—especially with the argument that life can be understood in terms of the same general laws that apply to all matter.

CHAPTER 5 **LIVING CHEMISTRY** 93

Even though all forms of life—all living organisms—exist in full compliance with the laws of chemistry and physics, the laws are those of *complex* chemistry and *complex* physics. Living organisms are composed of atoms that are common in the nonliving world, but these atoms are much more complexly organized than in nonliving matter. Only in living structures are atoms found organized into large molecules of nucleic acids, proteins, carbohydrates, and fats The cells of all living creatures are composed of these same classes of chemical substances.

CHAPTER 6 **THE PHYSIOLOGY OF CELLS** 118

Living cells, with their huge number of complex chemical substances, exhibit ceaseless chemical activity. Substances are entering and leaving the cells at all times, as molecules are being built up and broken down within the cells. This ceaseless chemical activity *is* life. Chemical energy is required for many of the reactions, and this energy comes from a single substance—ATP. The energy in ATP originally was the energy of the sun's light.

CHAPTER 7 **THE REPRODUCTION OF CELLS** 140

The most basic characteristic of life is reproduction, that is, the production of new structures and individuals similar to the existing structure or individual. Reproduction occurs at all levels of organization. Parts of the cell, such as the chromosomes, produce new chromosomes. Cells then produce new cells; and individuals, offspring like themselves. In this chapter, reproduction is discussed at one of its fundamental levels—the reproduction of cells.

CHAPTER 8 **THE BALANCE OF NATURE** 154

The living organisms of today are the product of a long series of evolutionary changes—changes that began when life first appeared on earth. These changes have represented an interaction between individuals and their physical environment, and between each individual and all others. Interaction occurs at all levels—from the level of a cell's molecules to that of the entire living world. This chapter ends the first section of the book—a section emphasizing the fundamental unity of all living things. But the eight chapters within the section do more: they lay a firm foundation for an understanding of the methods by which knowledge in science is obtained, interpreted, and used in seeking more knowledge.

PART 2 DIVERSITY

Diversity among the earth's microorganisms, plants, and animals is more obvious in many ways than the fundamental unity in life. Historically, diversity emerged as modifications upon a common pattern. Unity continues to be shown in the recognition that different organisms are similar chemically, have a common structural basis (cells), reproduce, evolve, respond to stimuli, and constitute parts of an interrelated whole. Yet diversity in life is seen in the millions of different types of living organisms, the three principal groups being microorganisms, plants, and animals. This section of the book will be concerned with the many variations upon the fundamental theme.

A. MICROORGANISMS

CHAPTER 9 **VIRUSES—THE SMALLEST LIVING THINGS** 181

No living thing is simple, but relatively speaking, the viruses are the simplest forms of life. They cannot in any way provide for themselves—they live only in cells of bacteria, plants, and animals. The host cells provide energy for the virus particles and materials for their reproduction—and often are killed in the process.

CHAPTER 10 **BACTERIA—PIONEERS OF CELLULAR ORGANIZATION** 192

The bacteria, a step more complex than the viruses, are the simplest organisms that can be called cells. They also are the smallest organisms that can be studied with the compound microscope. Their activities are the basic ones that are characteristic of *every* living organism. Life in the simplest cells can be very complex—even to reproduction by sexual means.

CHAPTER 11 **SMALL ORGANISMS OF GREAT ECONOMIC IMPORTANCE** 207

The bacteria, in spite of their microscopic size, are essential organisms in the complex web of life. Some species are of prime importance in the carbon and nitrogen cycles, which make possible the life of other plants and animals. Other species are used in a variety of manufacturing processes. Still other species cause diseases—in man as well as in other animals and plants. The discoveries leading to the proof that bacteria can produce disease furnish one of the most interesting examples of the methods of science.

B. PLANTS

CHAPTER 12 **MOLDS, YEASTS, AND MUSHROOMS** 231

Collectively known as fungi, the molds, yeasts, and mushrooms are more complex than bacteria. They represent distinctive lines in the evolution of organisms that cannot carry out photosynthesis. They, like the animals, are dependent ultimately upon the green plants. The fungi are important in the nitrogen cycle and other cycles of life. Together with the bacteria they are the chief decomposers—they break down the bodies of dead animals and plants and release substances that are needed by the living.

CHAPTER 13 THE TREND TOWARD COMPLEXITY 243

The most successful line of plant evolution gave rise to the green plants, of which the simplest are algae. Algae are of slight importance on land, but they are essential for life in the sea. They are the primary producers, using the energy of the sun to combine carbon dioxide, hydrogen, and nitrogen compounds to form the organic compounds of their own cells, which in turn become the food of animals.

CHAPTER 14 THE LAND TURNS GREEN 260

More than 400 million years ago, "enterprising" species of algae evolved into plants that could live on land. Until then, the land had been barren and lifeless. Slowly the earth grew a mantle of green—the life-supporting green of photosynthetic organisms. Special structures and processes, primarily for obtaining water, carbon dioxide, and nitrogen compounds—and for preventing subsequent loss of water—became necessary for plant life on land. The liverworts and mosses of today are reminders of some of the early experiments in the evolution of green land plants.

CHAPTER 15 PHOTOSYNTHESIS—THE LINK BETWEEN TWO WORLDS 286

Life is the child of light. Green plants capture the energy of sunlight and use it to synthesize energy-rich compounds. These compounds are the sole source of energy for nearly all other organisms. The essential substance in green plants that makes photosynthesis possible is chlorophyll, which in most land plants is concentrated in leaves.

CHAPTER 16 STEMS AND ROOTS—A STUDY OF COMPLEMENTARITY OF STRUCTURE AND FUNCTION 301

Land plants have stems and roots; plants of the open seas do not. The nature and the need of these familiar plant structures is one consequence of the difference between obtaining the necessities of life from air and the soil and obtaining them from the waters of the oceans.

CHAPTER 17 REPRODUCTION AND DEVELOPMENT IN FLOWERING PLANTS 317

The pinnacle of evolutionary development of the green plants is the large group of flowering plants. Most of the familiar plants of the world are flower-producing species. It is this group that provides directly or indirectly for nearly all of man's needs—his food, shelter, and most of his clothes and fuels. The reproduction of these plants is perhaps the only guarantee that nature affords civilization.

C. ANIMALS

CHAPTER **18** **THE WORLD OF ANIMALS** 337

Green plants are producers; animals are consumers. Given a proper temperature and the necessary inorganic substances, green plants can live wherever there is light. Animals can live only where there are green plants, or where there are products of green plants. This basic dependence defines the boundaries of the world of animals.

CHAPTER **19** **PARAMECIUM AND THE ANIMAL WAY OF LIFE** 343

The animal way of life—whether of a single-celled organism such as *Paramecium* or of large and complex animals—makes a series of demands on the world of life. What these demands, or requirements, are can be understood from the study of one kind of animal and its dependence upon other organisms and upon the nonliving environment.

CHAPTER **20** **THE DIVERSITY AMONG ANIMALS—VARIATIONS ON A THEME** 358

There are probably 2 million species of animals living today. Fundamentally, all live the same way, but in detail they vary tremendously. The many animal species can be classified into major goups known as phyla. Ten of these phyla include at least 98 percent of all known animals.

CHAPTER **21** **DIGESTION IN MULTICELLULAR ANIMALS** 380

In animals that consist of many cells, there is always some degree of specialization among the cells—a division of labor. Some cells may be specialized in capturing food, others in digesting it, still others in coordinating these activities and additional ones. Digestion is carried out in a simple sac (in *Hydra*) or a complex sac (in planarians), a simple tube (in some worms) or a complex tube (in grasshoppers and many other animals, including man). This chapter is a study of one essential aspect of this division of labor—the enzyme-controlled breakdown of food substances.

CHAPTER **22** **TRANSPORTATION WITHIN MULTICELLULAR ANIMALS** 398

Multicellular animals require a mechanism for transporting materials throughout the body. Sometimes simple diffusion will suffice, as in *Hydra*, but diffusion can supply only the requirements of very small bodies. Bodies of moderate or greater size and complexity have blood systems. How these are constructed and how they function is the subject of this chapter.

CHAPTER **23** **RESPIRATION IN MULTICELLULAR ANIMALS** 412

In all animal cells, hydrogen and carbon dioxide are waste products of energy-liberating reactions. Oxygen is required to eliminate the hydrogen (which combines with the oxygen to form water). Carbon dioxide leaves the body by simple diffusion, or with the help of some system of transportation (such as a circulatory system). All events relating to oxygen and carbon dioxide exchange, including the energy-liberating reactions within cells, are a part of respiration.

CHAPTER 24 EXCRETION IN MULTICELLULAR ANIMALS 421

The removal of the waste products of metabolism is known as excretion. In addition to hydrogen and carbon dioxide, a major kind of waste product in animals is one or more nitrogen compounds, such as urea. Respiratory processes eliminate hydrogen and carbon dioxide, but nitrogen compounds (except for ammonia in the less complex animals) are a separate problem. These nitrogen-containing, or nitrogenous, wastes usually must be removed by specialized excretory organs, such as kidneys.

CHAPTER 25 COORDINATION IN MULTICELLULAR ANIMALS 431

In all organisms there are homeostatic mechanisms that tend to keep the cells, tissues, and organs of the body at nearly constant conditions. Multicellular animals, with their many types of specialized cells, have some means of coordinating the activities of all the parts. Coordination is brought about in two general ways: control by nerves and control by special substances known as hormones. Information and "orders" are carried from one part of the body to another by both the nerves and the hormones.

CHAPTER 26 ANIMAL SUPPORT AND LOCOMOTION 449

Possibly the most obvious, though not the most diagnostic, characteristic of the animal way of life is movement. Single-celled animals may move by cilia, flagella, or by a flowing motion of the cell itself. More complex animals move by means of paddles, tentacles, wings, feet, fins, and sometimes even by cilia. In many instances the movement is dependent upon the contraction of specialized muscle cells—contraction made possible by special chemical reactions and the energy of ATP. Among the more complex animals, body movement usually involves supporting structures for the body—a skeleton on the inside, as in man, or on the outside, as in the insects.

CHAPTER 27 REPRODUCTION IN ANIMALS 462

Reproduction, the prime attribute of life at all levels, is studied in this chapter at the level of the individual, the organism. Reproduction may be asexual, as when a single-celled animal divides into two. In most animals, however—even those that can reproduce asexually—there is (or is also) sexual reproduction. This involves the production and union of an egg and a sperm. Sexual reproduction—so widespread in the living world that we must assume it to be the best type so far evolved—provides for many different combinations of genes (the hereditary material of the chromosomes) from among the total number of genes that are present in the parents. The combinations of genes as they occur in offspring are then tested by natural selection, and those that are superior help the offspring survive to produce the next generation of their species.

CHAPTER 28 **THE DEVELOPMENT OF ANIMALS** 482

In sexual reproduction the union of a sperm and an egg produces a fertilized egg. The fertilized egg is only a single cell and, hence, is vastly different from the multicellular adult. The events that occur during the gradual growth and change from fertilized egg to adult are known as development. Basically, development consists of an increase in the number of cells, the differentiation of cells into different types, growth, and the organization of cells into the structures of the adult.

CHAPTER 29 **THE ANALYSIS OF DEVELOPMENT** 494

For centuries man has speculated on the underlying factors that control development. Are individuals preformed in miniature in the sperm or the egg? Or, is it possible that one cell—necessarily of only one type—produces all the different kinds of cells of the adult organism? The latter seemed improbable, in view of what was known about cell divisions (cells normally divide to produce other cells like themselves). Yet the former idea appeared clearly impossible, except to the most imaginative of observerers. The secret of development has been well kept until recent years.

PART 3 CONTINUITY

Living organisms of today are the temporary manifestations of a lineage of life that extends backward in time for several billion years. Individuals die, but life continues in their offspring. Two aspects of the continuity of life by reproduction must be considered: a short-term continuity based on resemblances between parents and offspring, and a long-term continuity based on changes and their accumulation, through evolution.

A. GENETIC CONTINUITY

CHAPTER 30 **PATTERNS OF HEREDITY** 507

A fertilized egg is always of insignificant dimensions when compared with the adult it later forms. Yet this single cell contains all the information necessary for its development into a full-grown organism. Heredity is the process by which this information is transmitted from one generation to another, in exact and predictable ways, as set forth in the laws discovered by Gregor Mendel and by others in the century since Mendel's work.

CHAPTER 31 **THE CHROMOSOME THEORY OF HEREDITY** 527

The exact and predictable nature of inheritance suggests that it has a physical basis in the cell. During the first quarter of the twentieth century, biologists discovered this physical basis: the information of inheritance is carried by genes, which are parts of the chromosomes. The arrangement and distribution of chromosomes during the formation of eggs and sperms, and the particular combinations of chromosomes that occur at fertilization, determine the pattern of heredity. There is also a physical basis for recombination of genes located on the same chromosome.

CHAPTER **32** **GENES AND HOW THEY ACT** 548

In the past eighty years, biologists have located the physical basis of inheritance first in the nucleus, then in the chromosomes, and finally in the chemical nature of the genes. In nearly all organisms, each of the genes is in the form of a double strand of DNA. How does this substance code and transmit the "instructions" for producing and maintaining a complex organism? How does DNA control the production of even a single compound in an organism? The answer is being discovered today, as part of a theory that includes the concept of a one gene–one enzyme relationship, with "messenger" compounds running the essential errands of the genes.

CHAPTER **33** **GENES IN POPULATIONS** 573

Not only do genes control the life of an individual but, of course, the life of the species as well. The genetic makeup of the species is termed its gene pool. The gene pool is constantly changing as a consequence of mutation and of the action of the environment in selecting combinations of genes that best fit individuals for survival.

B. EVOLUTION

CHAPTER **34** **DARWINIAN EVOLUTION** 589

More than a century ago, Charles Darwin announced his theory of evolution—one of the most profound intellectual insights of all time. He offered a rational explanation for the innumerable different species that live on the earth—and for the changes that occur in them with the passage of time. Many biological phenomena became understandable in terms of the interaction of hereditary differences with environments in which some individuals survive to reproduce, while others do not. The fossil evidence of life long ago and the evidence derived from the study of life today substantiate the correctness of Darwin's theory.

CHAPTER **35** **THE MECHANISMS OF EVOLUTION** 611

In Darwin's time the available biological data were not sufficient to prove the correctness of the theory of evolution. More than half a century later, the careful study of inheritance did provide the necessary theoretical basis. We now understand the nature of hereditary differences among organisms and among entire species—a mystery to Darwin. From among genetically different individuals, those whose inherited characteristics best fit them to their environment are selected by nature; that is, those with the "better" gene combinations survive, whereas those with "inferior" gene combinations die out. Isolation—in terms of geographic barriers to mixing, and of gradually emerging genetic barriers to interbreeding—helps complete the separation of closely related populations into new species.

CHAPTER 36 THE ORIGIN AND THE HISTORY OF LIFE 633

Several billion years ago, when the earth was vastly different from what it is today, the primeval seas became rich mixtures of organic molecules. Probably a chance combination of molecules produced a larger molecule (similar to the DNA of today?) that had a chemical structure giving it a pattern for exact duplication. Slowly, the duplicating molecules became parts of more complex systems, until—perhaps after one or two billion years—they could be called "organisms." From these humble beginnings life spread over the earth and evolved into its innumerable species—each an experiment in living in a particular way.

CHAPTER 37 THE EVOLUTION OF MAN 657

The biological processes that affect all other life affect mankind as well. Man, too, has evolved—and has done so at a spectacular rate unequalled elsewhere in the world of life. About a million years ago he reached the stage at which he could be called "man" in the full sense of the term. Since then he has passed through a long childhood, as he slowly learned to use tools and fire and to communicate with his fellow man.

CHAPTER 38 THE CULTURAL EVOLUTION OF MAN 674

In the last 25,000 years man has changed little in his structure, but tremendously in his way of life. He has domesticated plants and animals and has solved, in increasingly better ways, a biological problem that he cannot escape—the need for food. He has built towns and cities and developed the science and technology that is the basis of civilization. His mind and hands have produced science, art, and literature. He has the information necessary to provide the individuals of his species with a secure and rewarding life.

C. THE LIVING WORLD—Today and Tomorrow

CHAPTER 39 THE LIVING WORLD 689

Among the biological problems that man cannot escape is the recognition that he is part of a living, changing world. The world of life could do without him—but he cannot do without it. Animals, plants, and microorganisms live as interdependent parts of communities, with habitats in the sea, the forest, the grassland, and even the desert. In each habitat, green plants are the primary producers, and other forms of life the consumers. The stockpile of materials in dead organisms is decomposed and returned to living circulation by bacteria, fungi, and other decomposers. All organisms are part of a great cycle that ultimately depends on the light of the sun.

CHAPTER 40 MAN AND THE BALANCE OF NATURE 707

Primitive man generally lived in balance with nature. He was an integrated part of the biological community. Civilized man, especially in recent centuries, has approached nature with an arrogance that could feasibly be his own undoing. By poor agricultural practices he has destroyed vast areas of productive soil; he has devastated forests, only to find his water supply diminishing and his soil supply eroding; he has fouled the rivers and streams, thereby making their water unsuitable to his needs. But today he is beginning to behave as he must—as a living creature who depends on other life for his own existence.

CHAPTER 41 **A PERSPECTIVE OF BIOLOGY** 720

In science, theories are more than ways of looking at things. They unite multitudes of separately puzzling observations into coherent conceptual schemes. There are many ways of organizing the data and relating the theories of biology—one of these ways, as the most promising today, seeks to account for the overall nature and for all the diversity of the world of life.

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