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BIOLOGY

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Frontispiece: Scanning electron micrograph of sea urchin sperm shortly after contact with the surface of the egg. By courtesy of Don W. Fawcett and Everett Anderson.

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(continued on p. 773.)

PREFACE

Biology— Today and Tomorrow

This book arises out of our conviction that, in its recent cataclysmic evolution, the science of biology has come of age. And, as in all the races and societies of man, "coming of age" brings with it new privileges and new responsibilities. By any reckoning, the responsibilities loom large.

As biology comes of age, so must its teachers and students. Biology, like its sister sciences chemistry and physics, which are themselves rapidly becoming part of the warp and woof of biology, has immense potential for both good and evil. The almost overwhelming advances in biomedicine and biomedical engineering—the development of antibiotics and vaccines and the fashioning of artificial organs; and in agriculture—the emergence of hybrid corn and other crops and livestock to feed the world—will soon be dwarfed by advances we are just beginning to perceive. But with these advances come responsibilities for larger decisions that will inevitably shape the lives of future generations.

As this book is being completed, one of the debates in the Congress and in the Courts centers on determining the vital balance between the need for increased power, to be provided by atomic plants, and the protection of the environment from radioactive and thermal pollution. The question is being asked in all seriousness, "Is a little pollution a good thing?" Which organisms are favored by raising the temperature of the ocean? Given the need for more electricity, where in the political process—and on what grounds—do we determine which is the lesser of two possible risks, radioactive and thermal pollution or pollution by the products of burning fossil fuels, products including cancer-causing hydrocarbons?

This question is related to another of great moment: The need for a vastly expanded program of cancer research. How does the public and its elected representatives determine whether the field of biomedicine is ready for a billion dollar a year program? How does it assess scientific evidence, especially when, as it so often happens, it is conflicting? Is there a conflict between "basic" and "relevant" research? Should we be preoccupied with "instant relevance?" How does information coalesce into ideas? How does research evolve into technological innovation? We know that for many innovations of great economic and social importance the "lag time" is long, measured not in months or years, but decades. One example, which we trace in Chapter 15, the oral contraceptive pill, required over sixty years of research in anatomy, physiology, systematic botany, and steroid chemistry, all of which would have come to naught but for the powerful stimulus of Margaret Sanger and other pioneers in the field of population control.

The atomic age was thrust upon a world unprepared for it. It is essential, we believe, that the impact of the biological revolution—its sweeping new concepts, its vast potential for technological advance, and its overwhelming social consequences—fall on "the mind prepared."

Strides are being made in capturing the drama of today's biology, in showing its emergence as an experimental science, and in fostering the inquiring mind. But at the same time the barrier to public judgment and understanding of the subject is increasing as the tide of new facts flows endlessly.

Thus there is a constant need for distillation and synthesis. This book is our distillation of biology. We have tried to provide for the beginning student the *essence* of the subject. Clifford Grobstein put it well when he wrote, in *The Strategy of Life*, that "Like science in general, biology is rooted in the substantial and the material." We have thus sought to convey the substantial and material facts about "life as external reality." But we have tried to convey *more* than selected facts and representative examples; we have tried to bring into focus the ideas of biology—their origin, testing and social impact.

We have paid serious attention to the social implications of biology. However our readers should not expect to find a single "catch-all" chapter on "social biology." We find merit in discussing the social implications of a discovery in the context of other findings to which it is related. Thus aging and "cells out of control"—cancer and congenital defects—are considered together with the mechanisms regulating development; and sterility resulting from "V.D.," and homosexuality and transvestism, are assessed against the background of the hormones in human reproduction. And so it goes: The origin of race and races is taken up as a question in population genetics, and pesticides and pollution are viewed in the context of environmental biology. Population control appears several times in our story, as seen through the eyes first of the reproductive biologist and then of the student of populations.

We have tried to make the book both timely and timeless. It is timely in the sense that new discoveries and insights are integrated into the text in sufficient depth to permit their full understanding. No subject has been ignored because it is distasteful or sensitive. At the same time, no subject is included just because "it always has been." The test is always: Is the idea important to an understanding of today's and tomorrow's world? In this sense the book is timeless.

Although we hope that a large audience will find our book useful to read without relation to a formal course of study, it is intended to be a *textbook for beginning students*. We agree with the sentiment voiced by Loewy and Siekevitz in introducing their *Cell Structure and Function*, that it is the beginner who deserves an initial statement that is fully representative of the contemporary quality and mode of the field. Thus we do not distinguish among beginners. We believe our book will be useful to beginning students no matter what their previous training or academic "track" may be. As we see it, our book can stand alone as a textbook for a one-semester course meeting the requirements of non-majors (but when does one become irrevocably "fixed" as a "non-biologist?"), or used in conjunction with paperbacks and other readings, as the text for a year's course for biology majors, whatever their preprofessional aims.

Our principal concern has not been the "package" or framework within which our readers will be receiving their training in biology. That responsibility rests with the instructor, who knows the background and experience and the motivations of his students. Rather, we have tried to convey the ideas of our subject, its spirit, and the sense of excitement surrounding it.

We have developed each topic gradually, but with sufficient rigor to make it meaningful no matter whether the instructor elects to follow the sequence we have chosen or whether he follows any one of several other equally valid routes to the same end.

For example, we have tried to offer an incisive treatment of cell regulatory mechanisms, leading up to a consideration of development and its controls, both the cell's inner controls and the environmental forces shaping development. We have worked hard to make topics which students traditionally find difficult, for example the electrochemical changes underlying the nerve impulse, clear and easy to remember. These key concepts are presented within the framework of a modern treatment of the nervous system and the physiological basis of animal behavior, including an analysis of the limbic system, motivation, learning, and the physiological effects of drugs.

Plants have been given major emphasis, with plant structure, function, diversity and development being treated extensively. In fact the sections on diversity of both animals and plants, with which the book is concluded, are, we believe, unique, recapturing the interest of natural history in a framework of modern comparative biochemistry, physiology and behavior.

The ideas of biology constitute an increasingly large part of our social heritage. More and more we are contemplating from whence we came. It was our late President, John F. Kennedy, who said: "All of us have in our veins the exact same percentage of salt in our blood that exists in the ocean, and therefore, we have salt in our blood, in our sweat, in our tears. We are tied to the ocean. And when we go back to the sea—whether it is to sail or to watch it—we are going back from whence we came."

And the President might have added that in our embryonic lives we spend some time in that "other ocean," the fluid of the amnion.

Thus we ponder our origins and our place in the universe. Our understanding of the living world about us is ever changing, ever expanding. If we are to face the future with confidence, we must understand how our ideas are rooted in the past—and nourished and winnowed in the present. It is toward that end that we offer this book.

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CHAPTER 1

The Biological Revolution

Three billion years ago life began on this planet. Whether it arose spontaneously from nonliving matter or was seeded by spores from a distant corner of the universe we do not as yet know. What followed, however, is becoming a well-chronicled drama, a sweep of accelerating events which has transformed our planet from a lifeless rock reflecting the rays of the sun to an intricate, teeming, minutely balanced living world in which the sun's energy and the materials of the earth are continually converted into the multitude of structures and processes of life.

This wonderful and complex planet of ours may not appear so very unusual to a spaceship approaching it from afar—to an astronaut 100,000 miles away the earth is but a small body spinning through space at 66,600 miles an hour, one of a group of nine planets circling in their orbits about the sun. In physical terms the earth is not especially remarkable; it is surrounded by a gaseous envelope, the atmosphere. It has a diameter of approximately 7900 miles and a circumference of about 25,000 miles. Its surface area of nearly 200 million square miles is about one-third land and the rest water. It has an inner solid core and a molten outer core, enclosed in a rocky mantle that extends to the earth's surface. However, what makes the earth unique in our solar system is that everywhere on its surface, on land, in its rivers, in its lakes and oceans, and for large distances into the atmosphere, there is *life*. And within this envelope of life that we call the **biosphere,** man is only one of a remarkable variety of organisms that have adapted to almost the entire range of physical conditions found on earth.

The highest human settlement in the world is in Chile at an altitude of 5700 meters (18,700 feet). Most humans would be starved for oxygen at this altitude and would be dizzy, weak, and unable to work. However, a few people and many species of animals have adapted to these high altitudes. Beetles live in the highest meadows of the Himalayas, earthworms are found at the extremes of cold and altitude at the snow line of the Andes, and eagles and vultures soar as high as 7000 meters.

At another extreme, marine animals have been collected from 10,500 meters below the ocean's surface at pressures of one ton per square centimeter; we will undoubtedly find living organisms at even greater depths when we have devised suitable apparatus for collecting them.

The lowest air temperature (−88°C) was recorded in Antarctica in 1960. Temperatures almost this low have also been recorded in the Yukon Territory of Canada on several occasions, and the plants and animals of the Arctic are obviously capable of surviving at temperatures this low and probably lower. More remarkably, the green alga *Chlorella*, a single-celled plant, has been frozen to −182°C and survived, and dry seeds of plants have germinated after three weeks in liquid air at −190°C. At the other extreme of temperature blue-green algae and certain bacteria live in hot springs (such as those in Yellowstone Park) at temperatures only 12 degrees centigrade below the boiling point of water.

Life is remarkable for reasons other than adaptability. The sweep of evolution has given rise to living systems which are increasingly able to *control* the conditions under which they live and thus escape the constraints and the capriciousness of their physical surroundings. Thus, for instance, while some organisms developed spores, eggs, or seeds which are able to survive drought or extreme cold, others evolved **warm-bloodedness** and thereby extended their range of life activities beyond that of their ancestors.

Man is a new arrival on this earth (Fig. 1-1); yet through the coupled evolution of his hand and his brain, the stage is now set for ever-increasing control of the arbitrary constraints of our environment to a degree which is still almost unimaginable. But before attempting to evaluate the magnitude and consequences of this *biological revolution*, we must ask ourselves how evolution—the upward sweep of the history of life on our earth—could have occurred, how living matter (more than other physical matter) is endowed supremely well with this ability to evolve.

LIVING MATTER USES ENERGY AND CREATES ORDER

There is a law of physics, the *second law of thermodynamics*, which asserts that **systems** *in isolation "run down."* Let us explain what we mean by "isolation" and by "running down," for the second law is an elusive concept unless one understands the meaning of each of its components in very concrete terms.

The most important concept of thermodynamics is energy, which is defined as the ability to do work. The word work has a familiar, everyday ring to it: we all have a feeling for what it is to do work and we all know that one needs energy to perform it. The work with which we are most familiar is mechanical work in which a force moves a mass through a given distance. But there are other forms of work along with their respective forms of energy. Electrical work can be performed by the expenditure of electrical energy, chemical work by chemical energy and so on. Furthermore, these various forms of energy are interconvertible so that chemical energy, for instance, can be transduced into mechanical energy and even vice versa. Living matter is particularly effective in performing energy transductions: our muscles convert chemical energy to mechanical energy that results in movement; when a firefly flashes its signal, it converts chemical energy to light energy; an electric eel converts the chemical energy stored in its "batteries" to electrical energy; the human eye converts light energy to chemical energy and then to electrical energy. Cells, the basic units of which all living organisms are composed, are specialists in converting one form of energy to another.

The important thing to recognize about these various forms of energy is that when they interconvert, they do so quantitatively, that is, without any energy being created or destroyed in the process. This is what the *first law of thermodynamics* states and numerous experiments have demonstrated that this law is obeyed just as scrupulously by living matter as it is by the heat engines investigated by the early students of thermodynamics.

To establish the first law, the systems under investigation had to be isolated from their environment so that no energy flowed between them and their environment. It was soon discovered that such isolated systems "ran down," that is, their ability to perform work decreased as work was being performed by them. The second law of thermodynamics was able to explain this important observation by distinguishing between **free energy** (G) and **enthalpy** (H) and showing how these two properties of matter are related to each other.

Free energy is that portion of the energy of a system which is able to perform work. When an isolated system performs work, the free energy of the system decreases. The enthalpy is the energy given off or absorbed and can be measured directly in an isolated system by the change in temperature which the system experiences. By studying heat engines it was soon discovered that free energy and enthalpy are not necessarily directly related to each other. That is, the loss of free energy during the performance of work by an isolated system is not necessarily equal to the increase in enthalpy associated with the process. It turned out that another term is involved in the equation. This term consists of two other properties of matter, one of which is the **absolute temperature** which is measured in Kelvin units. The other property is the **entropy,** which is related to the state of orderliness or organization of the system. The higher the state of organization, the lower is the entropy. The second law states that when a system performs work it runs down not only because the free energy decreases but because the entropy, its state of disorganization,

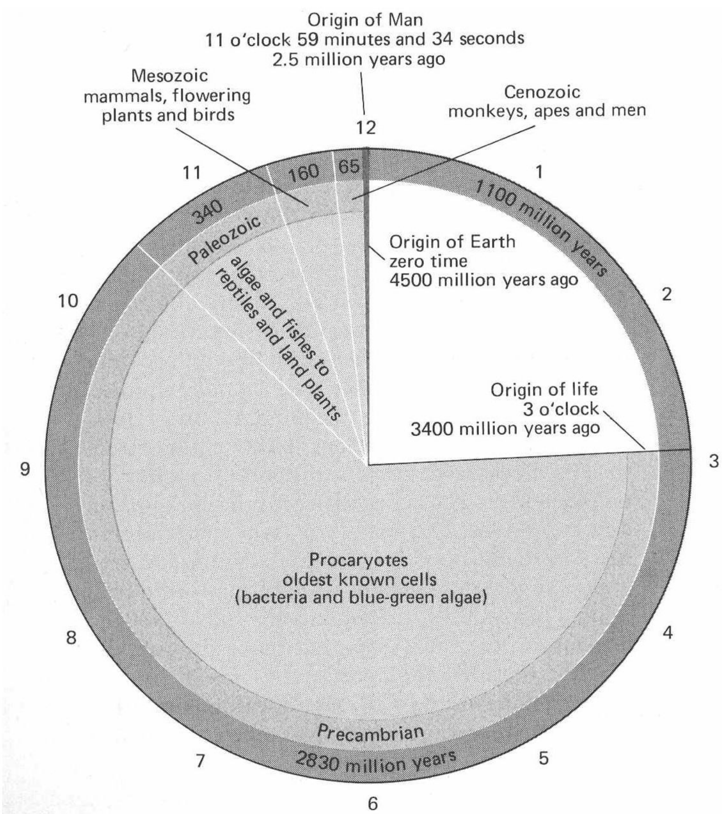

Figure 1-1 Man is a new arrival on the earth. If the age of the earth were 12 hours, then man has been on the scene for only 26 seconds. Notice how the pace of evolution accelerates, how the evolutionary periods become shorter and shorter.