THE CELL

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FOUNDATIONS OF MODERN BIOLOGY

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C A R L P . S W A N S O N

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FOUNDATIONS OF MODERN BIOLOGY SERIES

To **D.N.S.** *for many reasons*

Foundations of Modern Biology Series

The science of biology today is *not* the same science of fifty, twenty-five, or even ten years ago. Today's accelerated pace of research, aided by new instruments, techniques, and points of view, imparts to biology a rapidly changing character as discoveries pile one on top of the other. All of us are aware, however, that each new and important discovery is not just a mere addition to our knowledge; it also throws our established beliefs into question, and forces us constantly to reappraise and often to reshape the foundations upon which biology rests. An adequate presentation of the dynamic state of modern biology is, therefore, a formidable task and a challenge worthy of our best teachers.

The authors of this series believe that a new approach to the organization of the subject matter of biology is urgently needed to meet this challenge, an approach that introduces the student to biology as a growing, active science, and that also *permits each teacher of biology to determine the level and the structure of his own course.* A single textbook cannot provide such flexibility, and it is the authors' strong conviction that these student needs and teacher prerogatives can best be met by a series of short, inexpensive, well-written, and well-illustrated books so planned as to encompass those areas of study central to an understanding of the content, state, and direction of modern biology. The FOUNDATIONS OF MODERN BIOLOGY SERIES represents the translation of these ideas into print, with each volume being complete in itself yet at the same time serving as an integral part of the series as a whole.

Contents

The struggle to know is one of the most exciting dramas of history, and every man who ever tried to learn anything has enacted it for himself to some extent.

—RICHARD R. POWELL

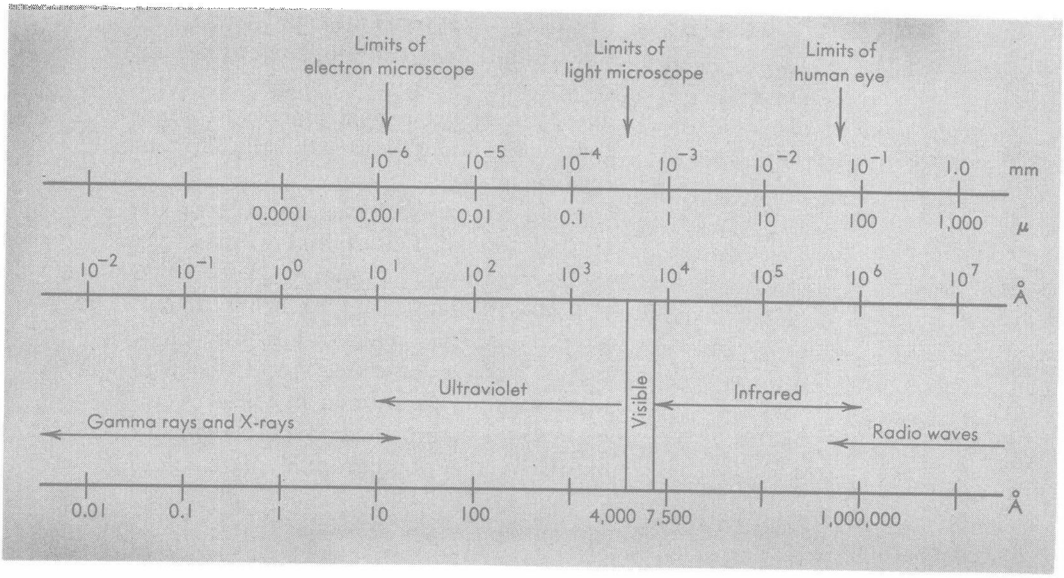
1 Introduction

The universe around us is not a continuum, a sort of pea-soupy structureless fog. Common experience tells us that it is made up of objects, matter, and other associated phenomena that we can describe or measure. We soon realize that each of these "things" has a uniqueness that we detect through touch, taste, hearing, smell, or sight, and that each is distinguishable to a greater or lesser degree. With our unaided senses, we have no difficulty in distinguishing the sky and the land from the water, a gas and a solid from a liquid, the living from the nonliving. On a more refined level, we can discriminate degrees of roughness, intensity and shade of color (provided we are not colorblind), and an acid taste from one that is salty, sweet, or bitter. But human powers of sensory discrimination are limited. We hear only within a certain range of sound waves, and see only a certain portion of the light spectrum (Fig. 1). When we try to go beyond these limits, we can no longer directly comprehend the physical nature of things and must resort to instruments to penetrate areas outside our naturally circumscribed sphere.

Instruments, therefore, act as extended senses. The 200-inch Hale telescope on Mount Palomar reaches across millions of light-years to bring distant galaxies of the macrocosm into view, while light microscopes and electron microscopes reach down into the microcosm to reveal otherwise invisible worlds. Similarly, the photographic plate, more sensitive than our eyes, extends our use of light rays. Ordinarily we can see only a minute portion of the electromagnetic spectrum, but by utilizing photosensitive surfaces we can detect the long infrared rays on one side of the spectrum and the short ultraviolet rays, X-rays, and even cosmic rays on the other.

By whatever means we use, the "things" we observe are called *units*, and the more refined is our knowledge and the more powerful and discriminating our instruments and techniques, the more precise becomes our definition of these units, i.e., their limits and their basic nature and function. If we are interested in classification, we find that these units often group themselves into meaningful systems. It would, indeed, be impossible for you to read these pages without understanding letters, the basic units of our language, or the numbers that make up our decimal system. The periodic table of atoms is another example of such a coherent system, and part of its great value lies in the fact that it enables us to predict what will happen under specified physical or chemical circumstances. The study of a related group of these systems quite often develops into a separate science. One of the first goals of a science, therefore, whether it be physics, chemistry, or biology, is to determine the uniqueness of the units with which it is concerned, for unless such units are understood and accepted by everyone in a particular field, scientific knowledge in it cannot progress.

Fig. 1. The electromagnetic spectrum on a linear log scale, measured in millimeters (mm), microns (μ), and Angstrom units (Å). Their relation to each other is as follows: 1 μ = 0.001 mm = 10,000 Å. At top are given the approximate limits of resolution of the human eye, the light microscope, and the electron microscope.



It should be pointed out that science makes use of two kinds of units. Those used to describe time, weight, and distance are arbitrarily defined, but we accept them as standards for the sake of convenience. Those such as the electron, proton, and neutron, however, have a demonstrated physical reality which can be independently determined by anyone having the proper instruments and required knowledge.

It is the latter type of unit that we will investigate here, for the basic unit of life, the *cell*, is a physical entity. We can break cells up and extract selected parts of them for study much as the physicist breaks up atoms. We find that these cellular fragments can carry on many of their activities for a time; they may consume oxygen, ferment sugars, and even form new molecules. But these activities individually do not constitute life any more than the behavior of a subatomic particle is equivalent to the behavior of an intact atom. The disrupted cell is no longer capable of continuing life indefinitely, so we conclude that the cell is the most elemental unit that can sustain life.

Compared to the atom and the molecule, the cell, of course, is a unit of far greater size and complexity. It is a microcosm having a definite boundary, within which a constant chemical activity is going on. The only chemically quiescent cell is a dead one. The function of *cytology* (the science of cells), therefore, is to recognize the kinds of cells that exist, to understand their organization and structure in terms of their activities and functions, and to visualize the cell not only as an individual microcosm (as it is, for example, in the unicellular bacterium) but also as an integral part of the more elaborate organs and organ systems of multicellular plants and animals.

Historical Background

The now familiar idea that the cell is the basic unit of life is known as the *cell theory* or the *cell doctrine*. Enunciated in 1839 by two German scientists, M. J. Schleiden and Theodor Schwann, the former a botanist and the latter a zoologist, the cell doctrine represented a decisive advance in the development of biological thought which now ranks with Charles Darwin's *evolution theory* as one of the foundation stones of modern biology. Indeed, we understand life itself only to the extent that we understand the structure and function of cells. As one scientist [1] has so aptly stated: "the cell concept is the concept of life, its origin, its nature and its continuity."

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[1] J. S. Karling, "Schleiden's Contribution to the Cell Theory," *Biological Symposia*, I (1940).

The emergence of a great scientific generalization is generally a slow accumulative process; very few men and their ideas stand alone in the stream of time. The significance of the date 1839 and of the names Schleiden and Schwann, therefore, does not lie in the fact that these men discovered cells, for the existence of cells had been known since 1665 when the Englishman, Robert Hooke, first saw them in a piece of cork under his primitive microscope (Fig. 2). It was Hooke, incidentally, who coined the word *cell* to designate the tiny structures he observed in the new world he had discovered. Nor indeed were Schleiden and Schwann the first to believe in, or advance, the idea that plants and animals were composed of cells and cell products; the Frenchman, Dutrochet, had stated this clearly some fifteen years earlier. The authors of the cell theory were, in fact, quite incorrect in some of their conclusions about the origin of cells. What they did do, however, was take the loose threads of old ideas and observations and weave them into a meaningful whole. Theirs

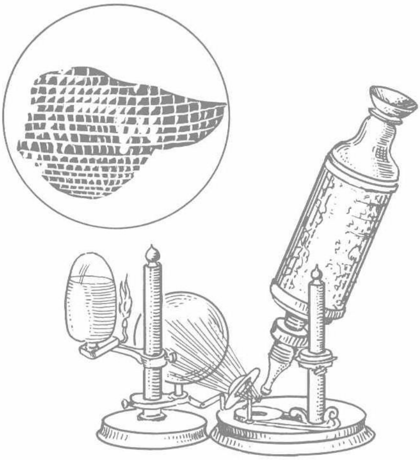


Fig. 2. Robert Hooke's drawing of the microscopic structure of cork (in circle), and the microscope with which he observed it. Here, in his own words, is a description of his experiment: "I took a good clear piece of Cork and with a Pen-knife sharpen'd as keen as a razor, I cut a piece of it off, and thereby left the surface of it exceeding smooth, then examining it very diligently with a Microscope, me thought I could perceive it to appear a little porous; but I could not so plainly distinguish them as to be sure that they were pores. . . . I with the same sharp pen-knife cut off from the former smooth surface an exceeding thin piece of it, and placing it on a black object Plate. . . . and casting the light on it with a deep plano-convex Glass, I could exceedingly plainly perceive it to be all perforated and porous, much like a Honey-comb, but that the pores of it were not regular . . . these pores, or cells, were not very deep, but consisted of a great many little Boxes, separated out of one continued long pore by certain Diaphragms . . . Nor is this kind of texture peculiar to Cork onely; for upon examination with my Microscope, I have found that the pith of an Elder, or almost any other Tree, the inner pulp or pith of the Cany hollow stalks of several other Vegetables: as of Fennel, Carrets, Daucus, Bur-docks, Teasels, Fearn . . . & c. have much such a kind of Schematisme, as I have lately shewn that of Cork."

was an act of synthesis and emphasis rather than of discovery, and by visualizing the cell as both the structural and functional unit of organization, *they defined the basic unit of life.*

Biology lagged behind the physical sciences in its definition of fundamental units. The Greeks as early as the fourth and fifth centuries B.C. speculated that all matter was composed of indivisible "atoms." Their concept, however, was more a philosophical idea than a scientific theory, since they failed to put it to a test or to inspire anyone else in the centuries following to do so. It remained for the Englishman, John Dalton, to accomplish in the early nineteenth century what the Greeks did not; his theory ascribed to the atom specific properties that not only explained many physical and chemical phenomena in a reasonable way but also indicated the directions in which systematic investigations of matter could proceed. In other words, *his theory defined the physical basis of matter and gave it predictable properties.* That Dalton's theory, like the cell theory, was not entirely correct is of small concern; what is important is that the two theories, by designating the fundamental unit of matter on the one hand and of life on the other, focused attention on the structures that had to be understood if the respective sciences were to progress.

Some twenty years after the announcements of Schleiden and Schwann, Rudolf Virchow, the great German physician, made another important generalization: that cells come only from pre-existing cells. When biologists further recognized that sperm and eggs are also cells which unite with each other in the process of fertilization, it became clear that life is an uninterrupted succession of cells. Growth, development, inheritance, evolution, disease, aging, and death are, therefore, but varied aspects of cellular behavior. It is with these problems, then, that we will be concerned in this book.

Exceptions to the Cell Theory

Most generalizations have exceptions to them which cast doubt on their universal validity. This is true as well for the cell theory, and the viruses in particular present a difficult problem.

Over three hundred different viruses are known. Many of them are the infective agents in such diseases as yellow fever, rabies, poliomyelitis, small pox, mumps, and measles in humans, and peach yellows and tobacco mosaic disease in plants. The plant viruses tend to be elongated structures, the animal ones spherical in shape (Fig. 3). If we apply to them our usual definition of a cell, they do not qualify as living organisms. Since they are so minute, we cannot see them except through an electron microscope, but we know that they lack the internal organization normally

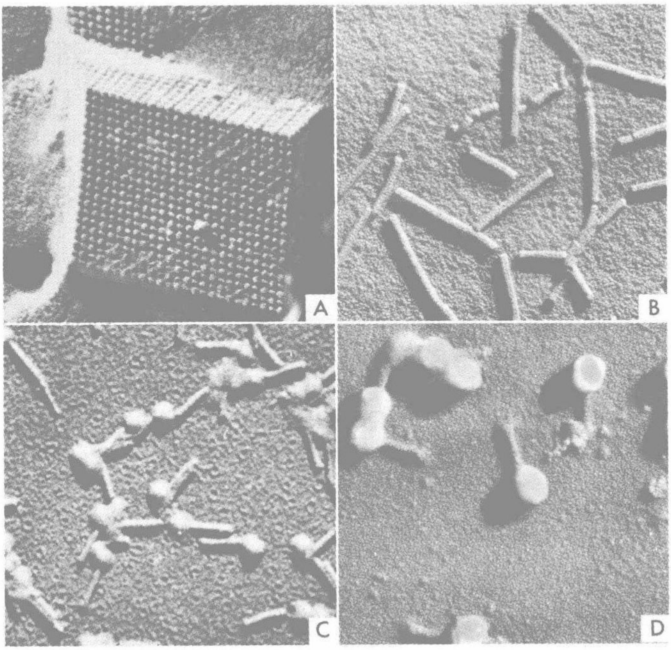
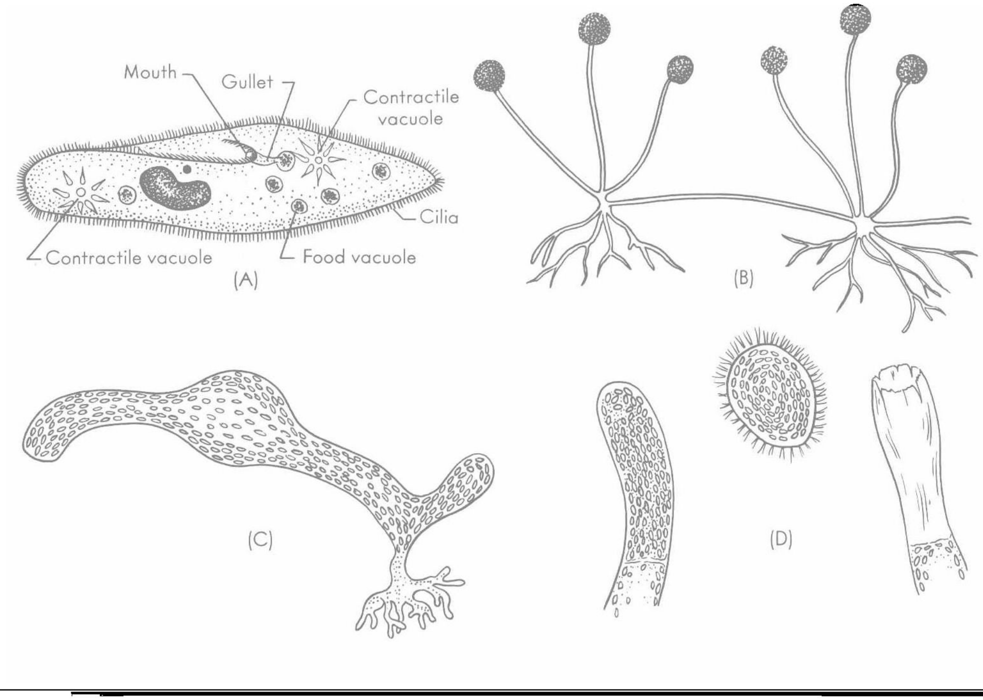


Fig. 3. Electron micrographs of viruses. (A) Tobacco necrosis virus; the virus particles are spherical in shape and about 250 Å in diameter, but when precipitated in ammonium sulfate they form a crystalline structure. (B) Tobacco mosaic virus; each rod is made up of a stack of plates similar to a stack of coins, with a protein coat on the outside and an inner core of ribose nucleic acid. (C) P2 bacteriophage or bacterial virus, which attacks the colon bacterium; each is equipped with a somewhat hexagonal head and a tail. (D) T6 bacteriophage, which also attacks the colon bacterium. (Courtesy of Dr. L. W. Labaw.)

Fig. 4. Organisms that should be considered acellular rather than cellular, since they lack cell walls. (A) *Paramecium*, the slipper animalcule, which has a mouth, a gullet for ingestion of food, food vacuoles for digestion, contractile vacuoles for excretion, and cilia for movement; (B) *Rhizopus*, the bread mold, with root-like structures to penetrate the surface, aerial branches to raise it into the air, and asexual reproductive structures at the ends of branches; (C) Young plant of *Vaucheria*, the alga which forms green mats on damp soil; (D) Reproduction in *Vaucheria* by the rounding off of a tip of a branch to form an asexual spore which will germinate to produce a new plant.



considered indispensable to a functioning cell. When they exist outside a living cell, they are simply inert molecules, although very elaborate and complex ones that may take a crystalline form. Inside a cell, however, where they are pathological parasites, they are clothed with the characteristics of life: they grow, multiply to produce exact replicas of themselves, and possess a type of inheritance not too far different from our own. They also contain the key molecules of protein and nucleic acid invariably found in every living organism.

Their ambiguous nature has led biologists to describe them in various ways: living chemicals; cellular forms that have degenerated through parasitism; or primitive organisms that have not reached a cellular state. Fortunately, we are not forced to decide whether a virus is or is not a cell, or even whether it is living or nonliving. The biologist generally treats them as if they were individual cells, and recognizes that their extreme simplicity of structure, when compared to a normal cell, makes them ideal objects for certain types of biological research.

Certain protozoa, algae, and fungi also provide exceptions to the concept that the cell is the basic unit of life. They appear to have abandoned the cell as a mechanical and structural unit, although their ancestral forms probably once had cells. The protozoan, *Paramecium* (Fig. 4), is seemingly a single cell, but it has a mouth or *gullet, contractile vacuoles* for the elimination of water and waste, other vacuoles for digestion, and many *cilia* (fine surface hairs) for motility. Although the point is debatable, *Paramecium* is probably best thought of as noncellular rather than cellular in nature.

A similar designation can be given to certain algae such as *Valonia*, or *Vaucheria*, or to fungi such as the black bread mold, *Rhizopus* (Fig. 4). They are simply a mass of living substance within an outer retaining wall, and it would be difficult to define the basic unit of such living bodies. These organisms, however, are related to cellular forms, so we can speculate that they have simply discarded the usual type of cellular organization for one that is mechanically better suited to their mode of existence.

Tools and Techniques of Cytology

Progress in the life sciences has not followed an even course, for it has been dependent on the development of more and more refined tools and techniques of analysis. This has been especially true for cytology. Some cells may be large enough to see with the unaided eye. But to identify their internal organization we must magnify them greatly and, more often than not, use dyes that stain selected parts of the cell and not others.