DOUGLAS MARSLAND

Principles of Modern
BIOLOGY

FOURTH EDITION

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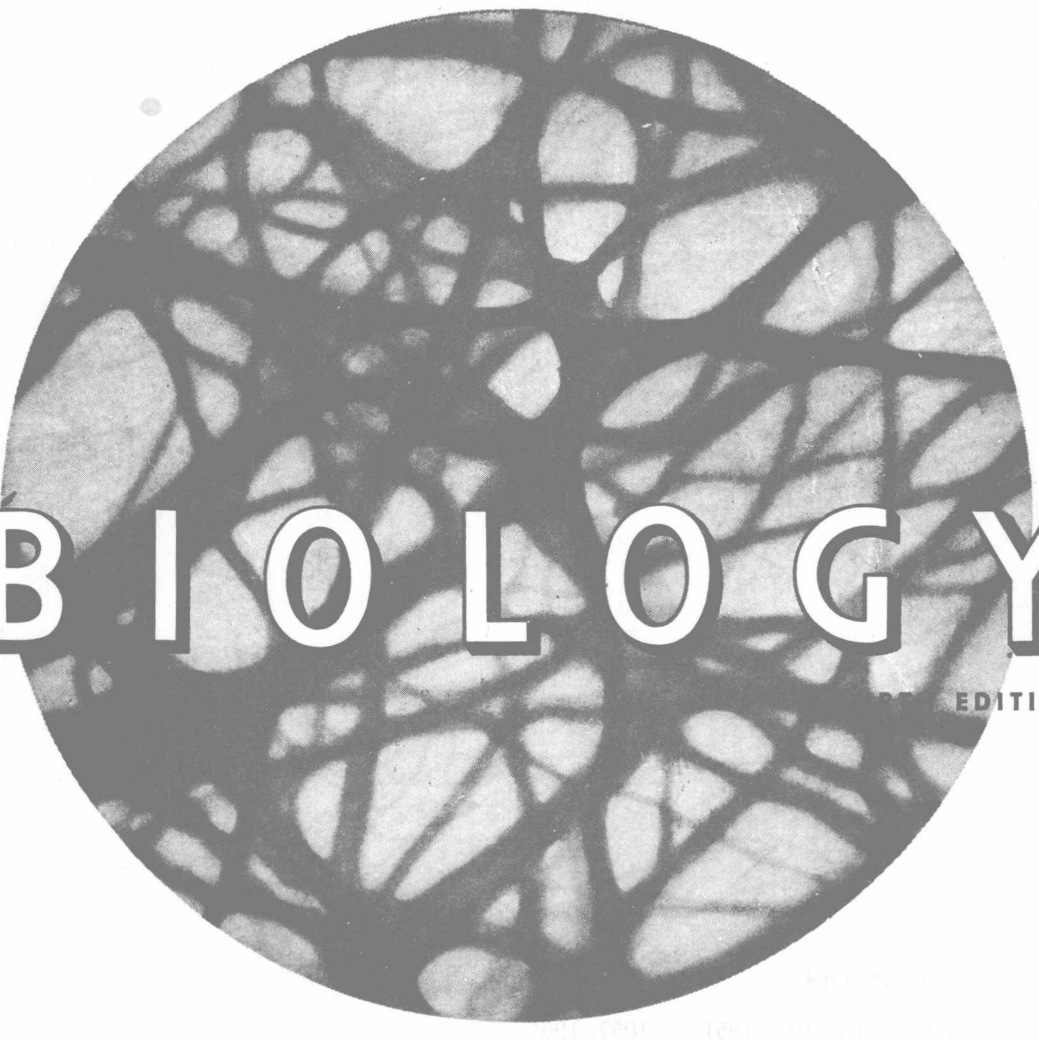
PART I-*The Cell*

Contents



BIOLOGY

EDITION

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New York • Chicago • San Francisco • Toronto • London

OCTOBER, 1964

Library of Congress Catalog Card Number: 64–11977
25470–0914
Printed in the United States of America

1–*Life and Protoplasm*

MORE THAN a million and a quarter distinct species of plants and animals are recognized in the world at large, and quite a number of newly discovered species are reported every year. Different organisms have evolved a special fitness to live in almost every part of the environment—in the ocean, on land, and in the air—under a wide variety of conditions. Certain species thrive on dry rocks and in stagnant swamps; in hot springs and in polar ices; where oxygen is abundant, and even where oxygen is lacking entirely.

Some organisms appear to be very simple—like microscopic droplets of clear liquid. But other creatures, like man, possess an obviously complicated structure. Gigantic living things, like whales or redwood trees, stand in dramatic contrast to the puniest bacterium, which looks like the smallest speck, even under the best magnification of the microscope. In short, a very rich diversity of living creatures has been evolved upon our earth, and man is challenged to reach an understanding of their nature (Fig. 1-1).

DISTINCTIVE ACTIVITIES OF LIVING BODIES

Since *biology* is the group of sciences that *deals with life* in all its forms and in all its activities, it is necessary to distinguish as clearly as possible between living and nonliving bodies. Such a distinction is not usually difficult, because living bodies are apt to

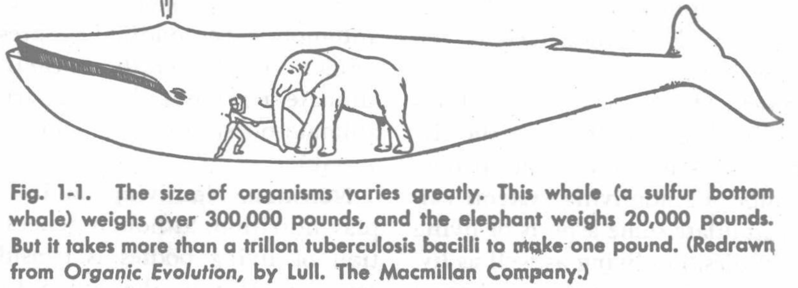

Fig. 1-1. The size of organisms varies greatly. This whale (a sulfur bottom whale) weighs over 300,000 pounds, and the elephant weighs 20,000 pounds. But it takes more than a trillon tuberculosis bacilli to make one pound. (Redrawn from *Organic Evolution*, by Lull. The Macmillan Company.)

display several unmistakable signs of life. All typical organisms are **responsive;** that is, all living things react to stimulation—by chemical agents such as food, or by physical agents such as light. Likewise, all living things sustain themselves by some kind of **nutrition.** Each takes in food from which to derive matter for growth and energy for movement. And above all, each kind of living thing displays a capacity for **reproduction,** perpetuating itself from generation to generation. In fact, these three activities—*responsiveness, nutrition,* and *reproduction*—are uniquely combined in living bodies, and can be taken as the main criteria of the **living state** (Fig. 1-2).

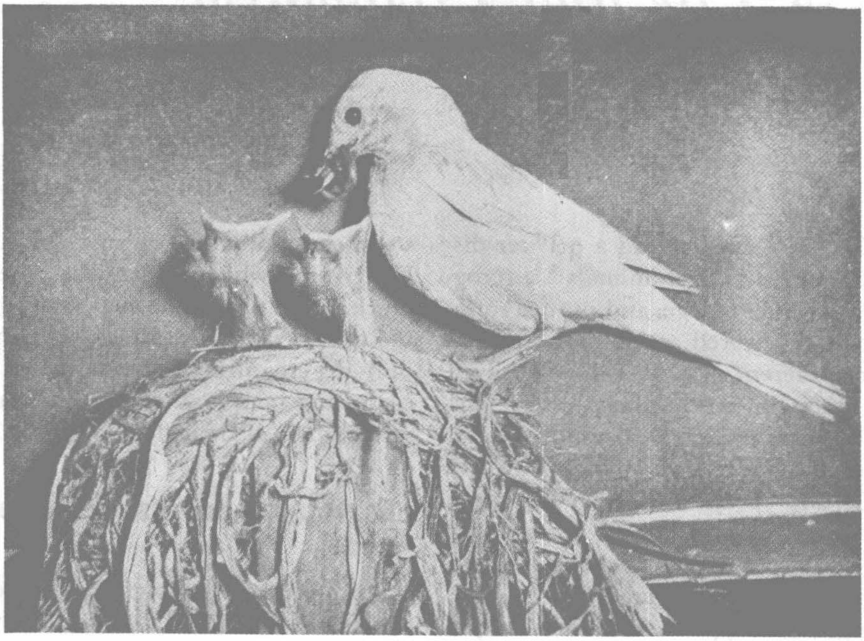

Fig. 1-2. Responsiveness, nutrition, and reproduction are characteristic of living things. Incidentally, this adult female robin is a fairly rare, white (albino) specimen. (Courtesy of Hugh M. Halliday.)

Responsiveness. One must conclude, however, that the dividing line between the living and nonliving is not a very sharp one, because a number of nonliving systems can be found that simulate some aspects of living behavior. All bodies, nonliving as well as living, are in some degree responsive; and some nonliving things display activities analogous to nutrition and growth. Water, or any other form of matter, continually alters its behavior in response to changes in temperature, pressure, light, and other factors of the environment. Water expands or contracts according to the temperature; it boils at one temperature and freezes at another. These are relatively simple reactions, hardly to be compared to the complex responses of a thinking man, or of a sprouting seed. But there are nonliving systems that are highly reactive—as for example, a loaded pistol responding to a touch on the trigger, or an automobile responding to pressure on the accelerator. Generally speaking, however, animate responses, in comparison with inanimate ones, are much more complex and variable.

Nutrition. Nonliving bodies may also display nutrition, although generally the nutrition of living bodies is considerably more complex. Within the living body, food always contributes both **energy**—the energy that activates the vital system—and **matter,** to form new components in the living structure. In other words, food in the living body can serve not only as a **fuel,** but also as raw material for chemical syntheses that provide for **maintenance** and lead to **growth.**

Many inanimate bodies utilize fuels, but few, if any, can grow or even maintain their existing structure. An automobile duplicates almost all the destructive phases of animate nutrition. It takes in fuel (food); it distributes the fuel to the carburetor; it sucks in (breathes) oxygen through the carburetor, which sends the fuel-oxygen mixture to the cylinders; it chemically decomposes (oxidizes) the fuel and utilizes the energy that is liberated for the development of mechanical power. Furthermore, the automobile must eliminate (excrete) the end products (waste products) of its chemical activities. But here the analogy stops. The automobile cannot grow. It cannot even replace the small structural losses that inevitably result from wear and tear. All the constructive phases of nutrition, by which new substances are synthesized and incorporated into the structure of the living body, are absent in all inanimate systems.

Growth and Reproduction: The Most Unique Activities of Living Systems. Biologists have tried to find a parallel to the characteristic **growth phenomena** of living bodies in the "growth" of crystals in a super-saturated solution. But this phenomenon seems much simpler than organic growth. Crystal growth follows a precise and characteristic pattern, but is altogether local and external. The crystal enlarges by the addition of new molecular layers at the *surface* only, and the enlargement is at the expense of molecules that exist as such in the surrounding solution. Organic growth, in contrast, pervades the entire protoplasmic mass, and depends upon an elaborate series of chemical changes leading to the formation of new components in the protoplasm. Or, from another point of view, organic growth depends upon a precisely patterned aggregation of many kinds of molecules, whereas crystals grow by the assemblage of one, or at most, two or three kinds of molecules.

The most unique characteristic of living bodies is the capacity for *reproduction;* and here it is hard to find any convincing inanimate examples. From the humblest bacterium to the mightiest mammal, each living species must maintain an unbroken line of descent, if it is to avoid extinction. The processes of reproduction are extremely complex and delicate even in the simpler forms of life. The formation of a new body, which is almost an exact replica of the old, presupposes the existence of a delicate mechanism that can sort out certain important components in each living organism and pass these on to each ensuing generation. These important *genic materials,* as we shall see (Chap. 26), possess not only the unique potential of *self-replication,* but also the capacity of providing templates for the replication of other essential components in each particular kind of living thing.

Certain inanimate bodies, namely crystals, may show an extremely simple form of "reproduction." Occasionally, while a small crystal is in the process of "growing," it will fragment spontaneously and each of the fragments will become the center around which a perfect new crystal will form. However, with the possible exception of the multiplication of the filtrable viruses (pp. 7-11), such a "reproductive" process is incomparably simpler than all cases of animate reproduction.

LIFE AND PROTOPLASM

To define life completely is scarcely possible, but the word can be used to designate the sum total of all activities—*responsiveness, nutrition, reproduction,* etc.—that are displayed by living bodies generally. Life, according to this usage, simply specifies "what living things do." It does not in any sense *explain* what they do, or *how* they do it.

Popularly the word "life" is sometimes used in a different sense: to designate a mysterious immaterial "something" that uniquely resides in living bodies, causing their activities. Science, however, has not been able to find the slightest evidence to confirm the existence of anything corresponding to this idea. Nor is such a concept useful. To say that a living body moves, responds, or grows "because it is alive" or because "it possesses life" is like saying that a motor runs "because it is motile" or "because it possesses motility." In science such so-called explanations are not admissible. The only scientifically valid kind of explanation consists in finding and describing an actual mechanism, in which the special composition, arrangement, and interaction of the component parts logically account for the observed activities.

In accordance with this important criterion of science, the aim of biology is to explain life—the activities of living bodies—in terms of the composition and structure of these bodies: what materials are present, how the component materials are uniquely organized in the living body, and how these components interact to generate the activities that are recognized as life. Just as the chemist or the physicist probes into the visible and subvisible structure of nonliving matter in seeking to understand the mechanism of its behavior, so the biologist, using essentially the same methods, investigates the ultimate structure of living matter, which is called **protoplasm.**

Protoplasm. The phenomena of life never find complete expression except in association with a particular kind of matter, namely protoplasm.

Typically protoplasm is a colorless, translucent, gelatinous fluid, which composes the living part of every living thing. All other parts of any living body—bone, cartilage, wood, etc.—are produced by the protoplasmic parts. **Protoplasm,** therefore, must be regarded as the *physical basis of life,* or, more simply, it may be referred to as **living matter.** In the ultimate composition and structure of protoplasm, the answers to life's unique riddles must be sought.

Chemical Structure. Protoplasm is not a single homogeneous substance. Rather, it is a complexly organized system in which many substances are present. Some of these substances, such as water and mineral salts, are also abundant in nonliving nature. But protoplasm is especially characterized by its rich variety of **organic substances, especially proteins,** which are found nowhere *in nature* except as components or products of protoplasm. The manifold chemical compounds of the protoplasm are constantly reacting and interacting. This ebb and flow of chemical activity, which is called **metabolism,** generates energy and provides for the synthesis of more organic compounds, needed as growth occurs. Moreover, the complex physical and chemical structure of protoplasm is *not stable.* It tends to disintegrate and become disorganized unless energy is constantly available for reconstruction. Just as an airplane cannot maintain altitude unless energy is available from the combustion of fuel in the motors, so the protoplasmic structure undergoes degradation unless energy is forthcoming from metabolism. The ultimate sources of metabolic energy may vary considerably in different forms of life (Chap. 9), but energy for immediate use is provided by a set of basic metabolic reactions that seem to be common to all protoplasm (Chap. 8).

Modern biologists now recognize that the physics and chemistry of protoplasm represent vitally important areas, and many research workers are active in these fields. Considerable attention will therefore be given to protoplasmic structure, particularly in Chapters 4 and 5.

Cellular Structure. It is generally recognized that protoplasm seldom, if ever, occurs in the form of any large continuous mass. Rather, it is subdivided into small unit masses, called **cells,** which usually are microscopic in dimension. Moreover, the protoplasm of every typical cell consists of two complementary and mutually dependent parts: a more or less central mass, the **nucleus** and a surrounding part, the **cytoplasm.** Both of these parts of the protoplasm possess an essentially similar chemical composition, except that certain of the proteins, namely the *DNA-nucleoproteins* (p. 90), are *distinctive of the nucleus.* This is a very important distinction, and will be explored more fully later (Chaps. 4, 8, and 27).

Each cell, essentially, is a living unit. Some small forms of life consist each of a single cell, and larger plants and animals are composed of many cells, variously modified according to their special functions in different parts of the body. Regardless of whether they are unicellular or multicellular, however, each specifically distinctive kind of living creature is designated as an **organism.**

Recognition of the **cell principle** (Chap. 2) did not reach full maturity until late in the nineteenth century. Nevertheless, this principle has had tremendous impact upon modern biology. Whatever activity is exhibited by a multicellular organism in performing the functions of responsiveness, growth, and reproduction represents the sum total of the activities of the component cells, working together as a beautifully integrated team. Accordingly, Part One of this book (Chaps. 1 to 11) will deal with single cells. This Part will attempt to analyze the structure and behavior of various basic cell types; the remaining Parts will be concerned mainly with the integrated behavior of the component cells of higher plant and animal organisms.

In the present century, particularly during the past 20 years, great advances have occurred that have enriched our knowledge of cellular structure and function. We now begin to understand the significance of many intracellular structures, or organelles. We know quite a bit about how **chromosomes** (p. 23) are constituted and how they are able to transmit coded directions in each cell; what the **nucleolus** (p. 23) is and how it is concerned with the synthesis of specific proteins in each cell; the nature of the **mitochondria** (p. 28), **ribosomes** (p. 25), and the **endoplasmic reticulum** (p. 23); and what roles these structures play in physiological activity. These and many other questions are being probed intensively by research workers throughout the world today. Final answers, of course, cannot be given, but the current status of the more important developments will be discussed in several later chapters.

All unequivocally living forms display a cellular structure, but there are some borderline cases, which must be mentioned now. These include two groups of exceedingly small infectious bodies—the **Rickettsia** (p. 580) and the **viruses.** Here, however, only the viruses will be discussed.

VIRUSES

Viruses are disease-inducing particles that are exceedingly small—so small in fact that their structure cannot be revealed by any type of light microscope (Fig. 2-10). Yet viruses display some properties that elsewhere are found only in association with living cells. It may be necessary, therefore, to qualify our concepts of the living unit, in light of further knowledge.

Ever since the dawn of biological curiosity, when the early cave men first began to draw pictures of the plants and animals that shared their environment, man has continued to discover and record new forms of life. Before the seventeenth century, when the microscope first revealed a whole new world of living minutiae, generation after generation of protozoans, bacteria, and other microscopic forms had lived and died without the blessing of man's cognizance. The biologists of that day were slow to admit these new organisms into the fraternity of life, and many years of research and controversy followed before the microorganisms were recognized generally. Today, it is the viruses that seem to lie at the boundary line between the living and the nonliving. If biologists finally conclude that the viruses are alive, then it will have to be admitted that a continuous intergradation exists between nonliving and living forms of matter.

The first virus was discovered by Iwanowski in 1892. Iwanowski found that juice squeezed from a tobacco plant afflicted with mosaic disease (Fig. 1-3), after passing through

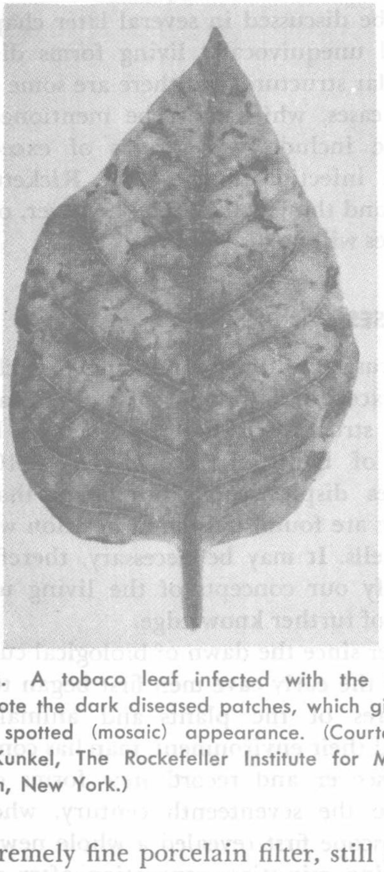

Fig. 1-3. A tobaco leaf infected with the mosaic virus. Note the dark diseased patches, which give the leaf a spotted (mosaic) appearance. (Courtesy of L. O. Kunkel, The Rockefeller Institute for Medical Research, New York.)

an extremely fine porcelain filter, still could give rise to the disease if brought into contact with a healthy plant. This was surprising since the clear filtered juice did not contain any particles large enough to be seen with any existing microscope. Previously in the nineteenth century, Pasteur, Koch, Reed, and others had demonstrated that many diseases in plants and animals are caused by microscopic parasites—such as bacteria and protozoans—which invade the tissues of other plants or animals. But in the present century it soon became apparent that other diseases must involve infective bodies much smaller and simpler than any known microorganism. Now, in fact, a fairly large number of virus diseases are recognized. These include smallpox, infantile paralysis, influenza, the common cold, and measles, for man; swine influenza, hog cholera, and bovine hoof and mouth disease for other animals; and the bacteriophages (Fig. 1-4) and mosaic infections of plants.

One unique feature of the viruses is the extreme smallness of the individual particles, each of which can be identified as being a complete virus unit. If one takes a fluid containing bacteria and forces this fluid through a porcelain filter (ultrafilter), the filtrate obtained is found to be sterile, that is, entirely free of bacteria. Apparently the pores of such a filter are so small that they prevent the bacteria from passing through. If, however, one ultrafilters a fluid containing the particles of a virus—such as the juice that can be squeezed from a tobacco plant infected with the tobacco mosaic disease, or the fluid derived from the brain of a monkey infected with infantile paralysis—the virus appears in the filtrate, quite undiminished in quantity.

Growth and Reproduction. Another important characteristic of the viruses is that each possesses, under the proper conditions, an unlimited capacity for growth and reproduction. Take, for example, the virus that gives rise to infantile paralysis in man and certain monkeys. This virus can be transmitted from monkey to monkey in endless succession, without any sign of limit. The smallest quantity of fluid from the brain of a diseased animal, implanted into the brain of a healthy monkey, leads in due time to paralytic symptoms in the inoculated animal. During the **incubation period**, the original minute quantity of virus increases to a tremendous extent. The virus spreads throughout all parts of the nervous system. Finally, every small fraction of the brain of the newly paralyzed animal contains as much of the virus as was originally introduced into the one localized site of injection.

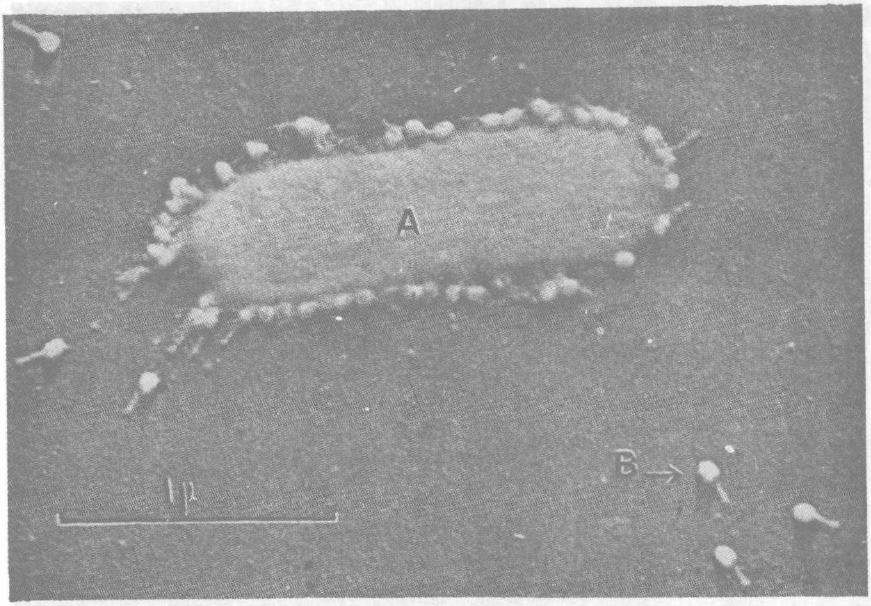

Fig. 1-4. An electronmicrograph showing a single bacterial cell (A) surrounded by many particles of bacteriophage (B). The marker (1 micron) shows the extremely small size of the bacterium *(Escherichia coli)* and the still smaller size of the bacteriophage particles (strain T_2). The bacteriophage destroys the bacterium when it penetrates the cell. In the present case, however, the clustering of the bacteriophage particles at the surface of the bacterium has resulted from drying the preparation—which must be done before an electronmicrograph can be taken. These specimens were shadow-cast with gold. (Courtesy of T. F. Anderson, University of Pennsylvania.)

Isolation of a Virus. In 1935 one of the viruses, the **tobacco mosaic virus,** was isolated and identified by W. M. Stanley, then at the Rockefeller Institute in New York City. To separate the virus from the many inactive components present in the total juice from an infected tobacco plant, two stages of centrifuging were employed. First, an ordinary low-speed centrifuge was used to remove all larger particles, such as bacteria and other microscopically visible bodies. This left a perfectly clear supernatant fluid that retained its infective potency in full strength. The second centrifuge was of the high-speed type, called an **ultracentrifuge.** Such a machine can develop centrifugal forces of about half a million times gravity. When a solution is subjected to this force, the larger **molecular** components tend to be thrown out of solution and to accumulate at the bottom of the test tube. In the present case, the sedimented material proved to be the virus in a practically pure condition. In other words, this sample of virus was practically free from contamination by any inactive materials. After further simple chemical treatment, the virus was obtained in the form of **crystals (Fig. 1-5)**

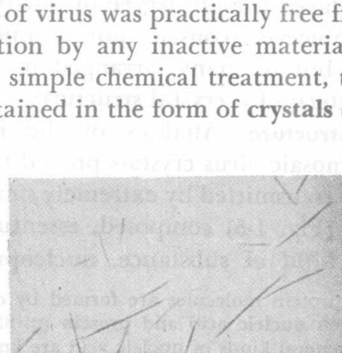

Fig. 1-5. Crystals of tobacco mosaic virus (× 675). Each crystal represents an aggregate of *many* virus particles. (Courtesy of W. M. Stanley, University of California.)

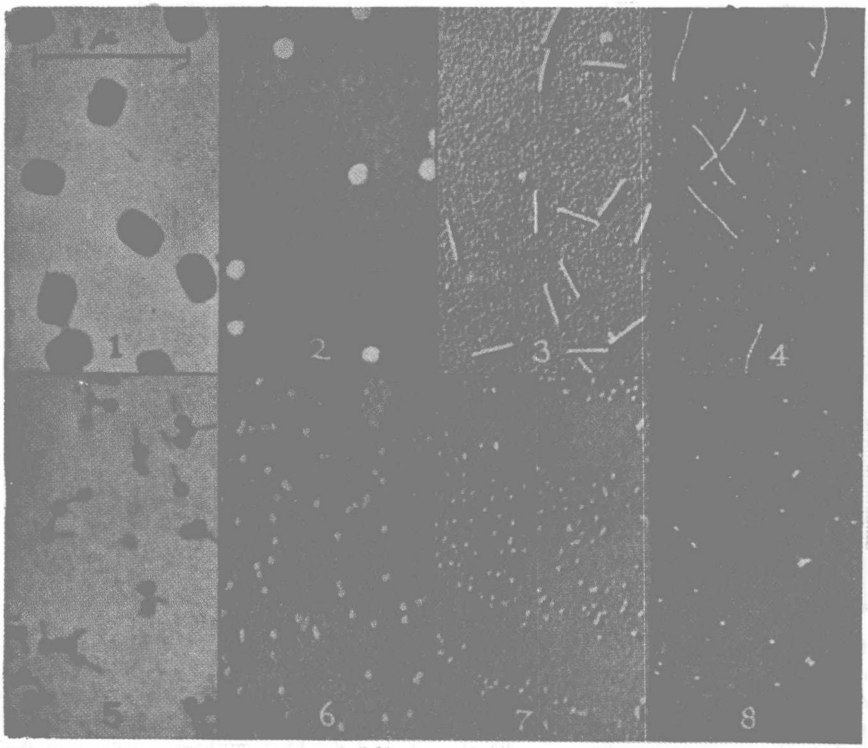

Fig. 1-6. The unit particles of different viruses vary considerably as to size and shape; and in some cases, more than one kind of molecule is represented in each virus particle. Electronmicrographs: 1. vaccinia virus, from smallpox vaccine; 2. influenza virus; 3. tobacco mosaic virus; 4. potato mosaic virus; 5. bacteriophage; 6. virus of the Shope papilloma; 7. southern bean mosaic virus; 8. bushy stunt virus of tomato. All except 1 and 5 were shadow-cast with gold. This technique permits the depth of each particle to be appreciated. (Courtesy of C. A. Knight, University of California.)

that displayed a high degree of purity. Each crystal, however, consists not of one virus particle, but of many, arranged in the orderly pattern of a **crystal structure.**

Unit Structure. Analysis of the isolated tobacco mosaic virus crystals proved that the disease is transmitted by extremely small unit particles (Fig. 1-6) composed, essentially, of a single kind of substance, **nucleoprotein.**[1]

[1] Nucleoprotein molecules are formed by combination between **nucleic acid** and **protein** (p. 83). However, two general kinds of nucleic acid are known: (1) DNA (deoxyribonucleic acid) and (2) RNA (ribonucleic acid), each having a slightly different chemical structure. The RNA proteins are present in the cytoplasm as well as in the nuclei of cells generally; but the DNA proteins, of which genes are composed, are restricted (except for viruses) almost entirely to nuclei.

The nucleic acid fraction of most viruses has proved to be of the DNA (deoxyribonucleic acid) type. Throughout all nature, such DNA proteins are recognized as the most essential components represented in the structure of the **genes,** the instruments of hereditary transmission in all organisms. The DNA proteins, indeed, show two very unique and important characteristics. Each is capable of engineering self-synthesis by providing a template that guides the synthesis of its own structure (p. 522). And in addition, the DNA elements of the cell may provide templates for the synthesis of other substances (Chap. 27).

The unit particles of different viruses are generally too small to be seen with any light microscope, but they can be resolved by the **electron microscope** (Fig. 1-6). Among viruses with spherical particles, the diameters range from about 17 millimicrons (mμ) for the alfalfa mosaic virus, to about 225 millimicrons (Fig. 1-6) for the vaccinia (cowpox) virus (used for vaccinations against smallpox in man). In some cases (for example, human influenza virus), traces of lipid (p. 80) and carbohydrate (p. 76) compounds are present, in addition to the nucleoprotein; and generally speaking the protein fraction of the particles is localized at the surface, forming a sort of envelope surrounding the nucleic acid.

Virus particles are much smaller and simpler than bacterial cells, which are perhaps the smallest cells. The bacterial cell is several thousand times larger and it contains a wide variety of chemical components—water, inorganic salts, lipids, and carbohydrates—in addition to proteins and nucleoproteins. In short, bacteria show a fairly typical protoplasmic structure. The simplest virus, on the other hand, may be a single large molecule of nucleoprotein or, at most, a complex of relatively few molecules. Consequently, if it ever is proved that viruses are truly alive, it will have to be admitted that the simplest forms of life are not much more complex than certain inanimate kinds of matter.

Are Viruses Alive? The crux of the question as to whether the viruses are truly alive lies in the fact that no virus has ever displayed any capacity for growth and replication, *except when the virus is inside some well-recognized kind of living cell.* When a virus particle makes contact with the proper kind of living cell, penetration occurs, but only the DNA fraction actually enters (p. 524). In the cell, the viral DNA rapidly undergoes self-replication and less than an hour later, usually, the amount of viral DNA has increased more than a hundredfold. Viral protein then begins to appear and the multiplication of complete viral particles has been achieved (p. 525). In other words, viral DNA, inside the host cell, behaves like a foreign gene, usurping the material that ordinarily would be used in the replication of the normal genes of the host cell itself (p. 522). The virus appears to provide a pattern that activates certain molecules present in the host cell to assemble and unite in such a way as to form new virus. Indeed, it sometimes happens that a certain virus may become incorporated into a chromosome of a host cell and thus be carried from cell generation to generation quite indefinitely.

The foregoing observations make it doubtful that the growth and replication of viruses represent a truly independent type of reproduction, such as is characteristic of living things generally. On the other hand, certain bacteria are obligatory parasites, which never reproduce except within some living host; yet no one is inclined to doubt the living status of these forms. Certainly viral replication bears a very close resemblance to genic replication (p. 522), which is an integral part of reproduction in all organisms. Many unsuccessful attempts[2] have been made to cultivate viruses and to induce them to reproduce in some medium in which no living cells are present. But unless or until such cultivation is achieved, we must continue to regard the viruses as more or less transitional between the living and nonliving forms of matter.

THE PROGRESS OF SCIENCE

A *science* is a systematically organized body of knowledge, based upon precise unbiased observation and integrated by logical reasoning. To the fullest possible extent, scientific knowledge is checked and counterchecked by carefully planned and strictly controlled experiments.

Without special training in scientific research, man has always been quite helpless in trying to understand the nature of his universe. In very early times man depended

[2] A recent report indicates that viral growth and replication has been observed in a cell-free medium. However, preformed DNA, extracted from cells, was provided in this medium.