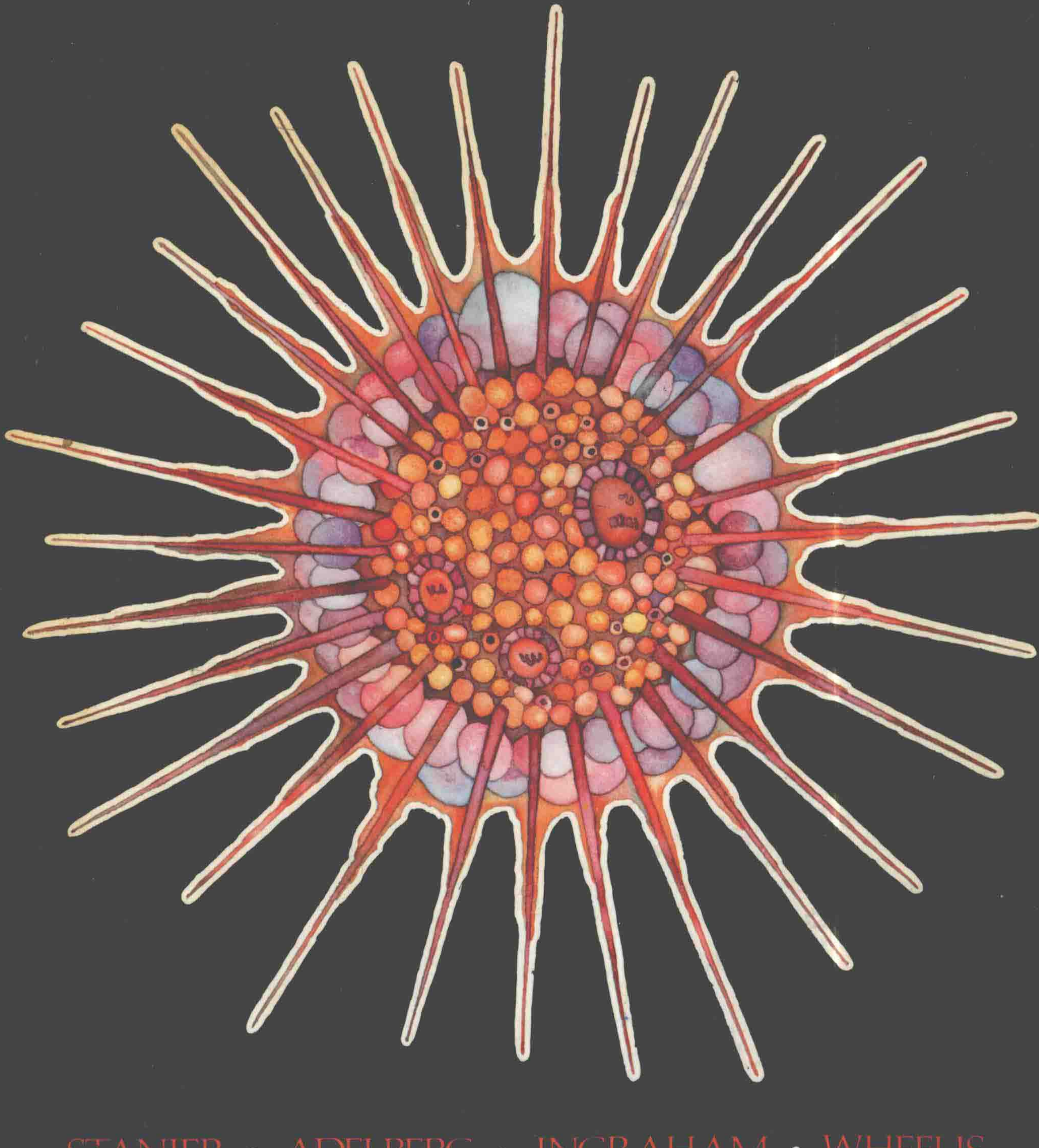
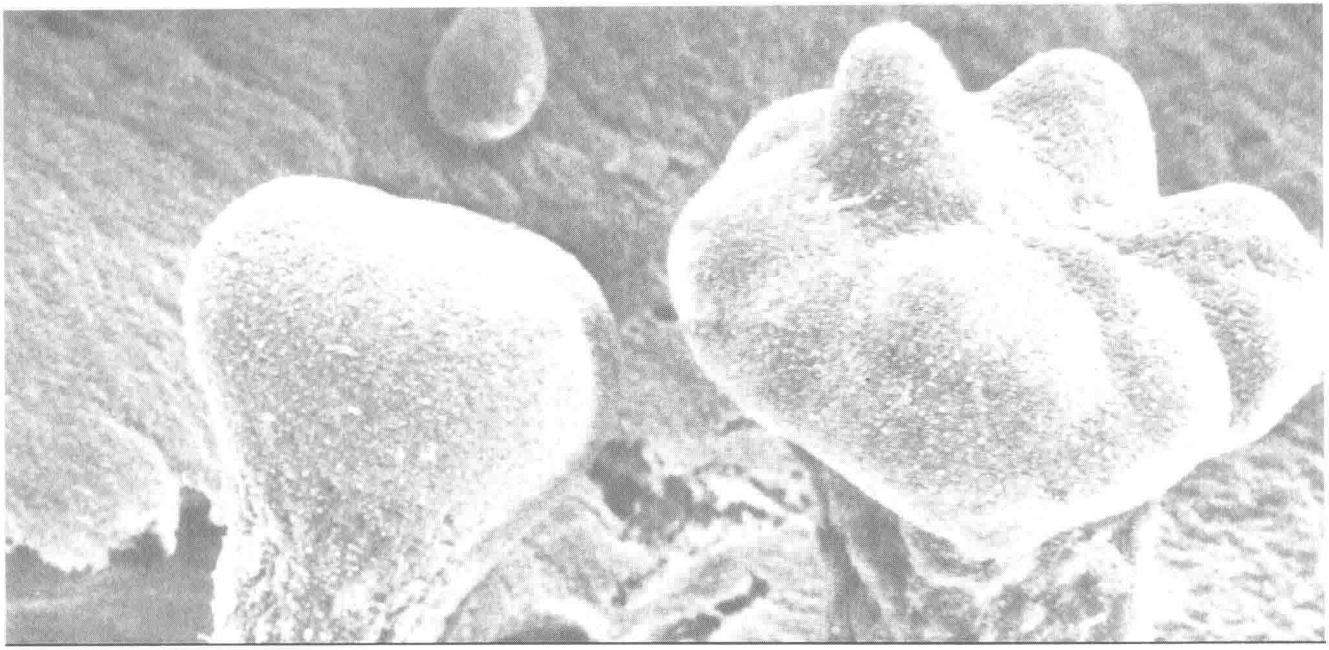


STANIER · ADELBERG · INGRAHAM · WHEELIS

INTRODUCTION TO THE MICROBIAL WORLD



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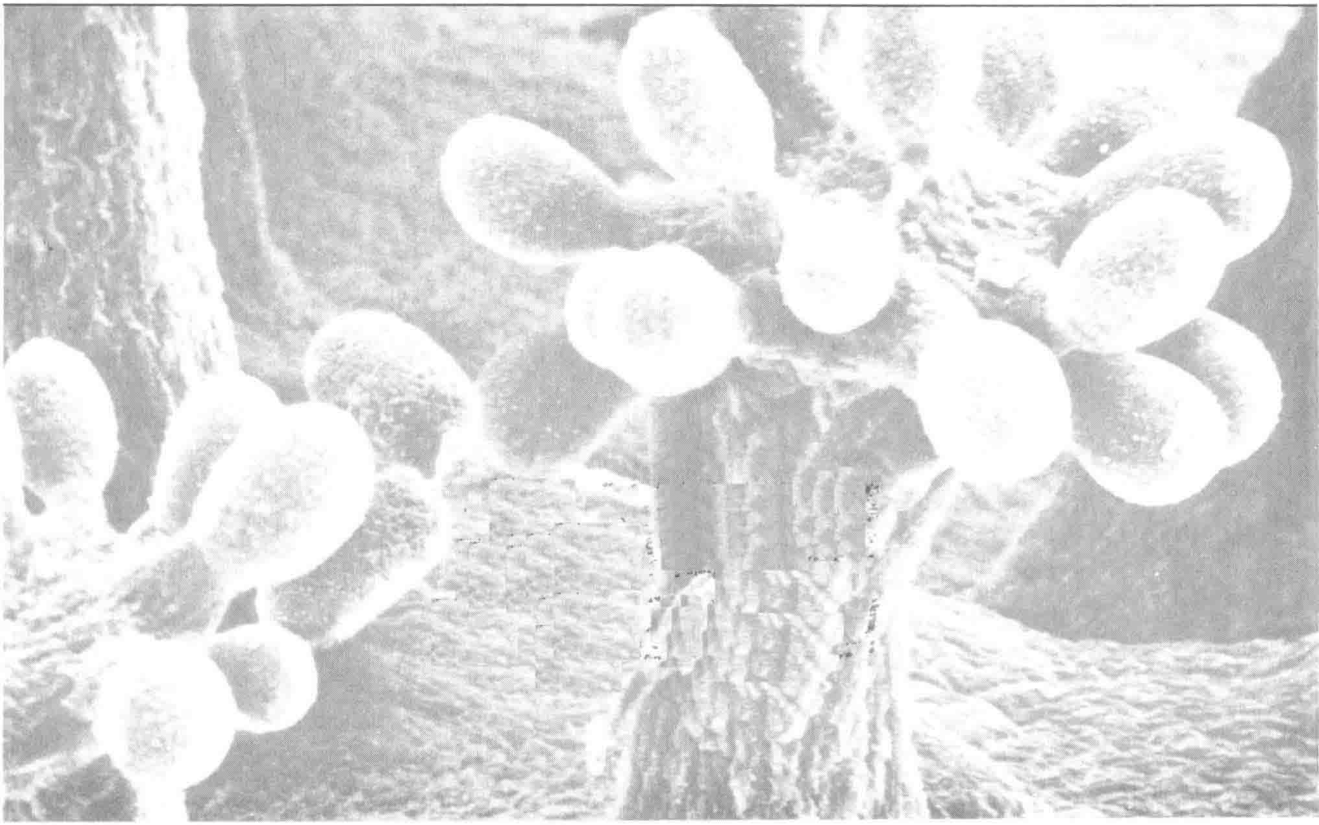

PREFACE

In 1955–1957, when the authors planned the first edition of *The Microbial World,* it was explicitly designed as "an attempt to present a modern synthesis of microbiological knowledge in a form intelligible to the beginner." It contained a special section—"The Biological Background"—for students not previously exposed to biology. The treatments of physiology and metabolism were low-keyed, and the embryo science of bacterial genetics was covered in a little more than 20 pages.

In later editions, each of which has involved a nearly complete rewriting of the book, the authors largely lost sight of the stated goal. "The Biological Background" was already jettisoned in the second edition (1963), and some knowledge of both organic chemistry and genetic principles was presupposed in the considerably enlarged sections that dealt with metabolism and genetics. The fourth and current edition of *The Microbial World* (1976) cannot pretend to provide an introduction for the beginner, in a course which spans either a semester or a quarter. Nevertheless, the authors have frequently regretted this progressive transmutation of their book, believing that its style and viewpoint, if not its scope and content, are very well-suited to a beginner. Extensive discussion of the problem has led to the presently greatly abridged and simplified *Introduction to the Microbial World* which is not intended to replace *The Microbial World* but to complement it. Once again, over 20 years after the first edition, we hope to present anew "a modern synthesis of microbiological knowledge in a form intelligible to the beginner."

R. Y. STANIER

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1

THE HISTORY OF MICROBIOLOGY

Microbiology is the study of organisms that are too small to be clearly perceived by the unaided human eye, called *microorganisms*. If an object has a diameter of less than 0.1 mm, the eye cannot perceive it at all, and very little detail can be perceived in an object with a diameter of 1 mm. Roughly speaking, therefore, organisms with a diameter of 1 mm or less are microorganisms and fall into the broad domain of microbiology. Microorganisms have a wide taxonomic distribution; they include some metazoan animals, protozoa, many algae and fungi, bacteria, and viruses. The existence of this microbial world was unknown until the invention of microscopes, optical instruments that serve to magnify objects so small that they cannot be clearly seen by the unaided human eye.

the discovery of the microbial world

Figure 1.1
Antony van Leeuwenhoek (1632–1723). In this portrait, he is holding one of his microscopes. Courtesy of the Rijksmuseum, Amsterdam.

The discoverer of the microbial world was a Dutch merchant, Antony van Leeuwenhoek (Figure 1.1). His scientific activities were fitted into a life well filled with business affairs and civic duties. He had little formal education and never attended a university. This was probably no disadvantage scientifically, since the scientific training then available would have provided little basis for his life's work; more serious handicaps, insofar as the communication of his discoveries went, were his lack of connections in the learned world and his ignorance of any language except Dutch. Nevertheless, through a fortunate chance, his work became widely known in his own lifetime, and its importance was immediately recognized. About the time that Leeuwenhoek began his observations, the Royal Society had been established in England for the communication and publication of scientific work. The Society invited Leeuwenhoek to communicate his observations to its members and a few years later (1680) elected him as a Fellow. For almost 50 years, until his death in 1723, Leeuwenhoek transmitted his discoveries to the Royal Society in the form of a long series of letters written in Dutch, which were translated and published, thus becoming quickly disseminated.

Leeuwenhoek's microscopes (Figure 1.2) bore little resemblance to the instruments with which we are familiar. The almost spherical lens (a) was mounted between two small metal plates. The specimen was placed on the point of a blunt pin (b) attached to the back plate and was brought into focus by manipulating two screws (c) and (d), which varied the position of the pin relative to the lens. During this operation the observer held the instrument with its other face very close to his eye and squinted through the lens. No change of magnification was possible, the magnifying power of each microscope being an intrinsic property of its lens. Despite the simplicity of their construction, Leeuwenhoek's microscopes were able to give clear images at magnifications that ranged, depending on the focal length of the lens, from about 50 to nearly 300 diameters. The highest magnification that he could obtain was consequently somewhat less than one-third of the highest magnification that is obtainable with a modern light microscope. Leeuwenhoek constructed hundreds of such instruments; a few survive today.

Leeuwenhoek's place in scientific history depends not so much on his skill as a microscope maker, essential though this was, as on the extraordinary range and skill of his microscopic observations. Indeed, it would be easy to fill a page with a mere list of his major discoveries about the structure of higher plants and animals. His greatest claim to fame rests, however, on his discovery of the microbial world: the world of "animalcules," or little animals, as he and his contemporaries called them. A new

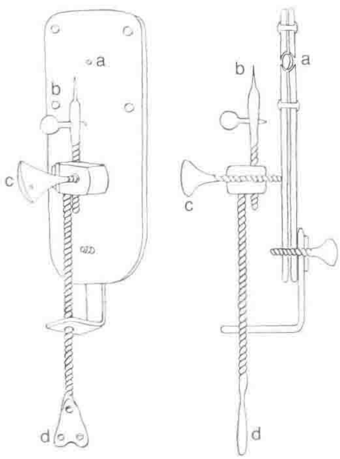

Figure 1.2
A drawing to show the construction of one of Leeuwenhoek's microscopes: (a) lens, (b) mounting pin, (c) and (d) focusing screws. After C. E. Dobell, *Antony van Leeuwenhoek and His Little Animals*. New York: Russell and Russell, Inc., 1932.

dimension was thus added to biology. All the main kinds of unicellular microorganisms that we know today—protozoa, algae, yeasts, and bacteria—were first described by Leeuwenhoek, often with such accuracy that it is possible to identify individual species from his accounts of them. In addition to the diversity of this microbial world, Leeuwenhoek emphasized its incredible abundance. For example, in one letter describing for the first time the characteristic bacteria of the human mouth, he wrote:

> I have had several gentlewomen in my house, who were keen on seeing the little eels in vinegar; but some of them were so disgusted at the spectacle, that they vowed they'd never use vinegar again. But what if one should tell such people in future that there are more animals living in the scum on the teeth in a man's mouth, than there are men in a whole kingdom?

Although Leeuwenhoek's contemporaries marveled at his scientific discoveries, the microscopic exploration of the microbial world that he had so brilliantly begun was not appreciably extended for over a century after his death. The principal reasons for this long delay seem to have been technical ones. Simple microscopes of high magnification are both difficult and tiring to use, and the manufacture of the very small lenses is an operation that requires great skill. Consequently, most of Leeuwenhoek's contemporaries and immediate successors used microscopes that suffered from serious optical defects. The major optical improvements that were eventually to lead to compound microscopes of the quality that we use today began about 1820 and extended through the succeeding half century. These improvements were closely followed by resumed exploration of the microbial world and resulted, by the end of the nineteenth century, in a detailed knowledge of its constituent groups. In the meantime, however, the science of microbiology had been developing in other ways, which led to the discovery of the roles the microorganisms play in the transformations of mattter and in the causation of disease.

the controversy over spontaneous generation

After Leeuwenhoek had revealed the vast numbers of microscopic creatures present in nature, scientists began to wonder about their origin. From the beginning there were two schools of thought. Some believed that the animalcules were formed spontaneously from nonliving materials, whereas others (Leeuwenhoek included) believed that they were formed from the "seeds" or "germs" of these animalcules. The belief in the spontaneous formation of living beings from nonliving matter is known as the doctrine of *spontaneous generation* and has had a long existence. In ancient times it was considered self-evident that many plants and animals can be generated spontaneously under special conditions. The doctrine of spontaneous generation was accepted without question until the Renaissance.

As knowledge of living organisms accumulated, it gradually became evident that the spontaneous generation of plants and animals simply does not occur. A decisive step in the abandonment of the doctrine as applied to animals took place as the result of experiments performed about 1665 by an Italian physician Francesco Redi. He showed that the maggots that develop in putrefying meat are the larval stages of flies and will never appear if the meat is protected by placing it in a vessel closed with fine gauze so that flies are unable to deposit their eggs on it. For technical reasons, it is far more difficult to show that microorganisms are not generated spontaneously, and as time went on the proponents of the doctrine came to center their claims more and more on the mysterious appearance of these simplest forms of life in organic infusions.

One of the first to provide strong evidence that microorganisms do not arise spontaneously in organic infusions was the Italian naturalist Lazzaro Spallanzani, in the middle of the eighteenth century. He showed that heating can prevent the appearance of animalcules in infusions. Spallanzani concluded that animalcules can be carried into infusions by air and that this is the explanation for their supposed spontaneous generation in well-heated infusions. Earlier workers had closed their flasks with corks, but Spallanzani was not satisfied that any mechanical plug could completely exclude air, and he resorted to hermetic sealing. He observed that after sealed infusions had remained barren for a long time, a tiny crack in the glass would be followed by the development of animalcules. His final conclusion was that to render an infusion *permanently* barren, it must be sealed hermetically and boiled. Animalcules could never appear unless new air entered the flask.

Spallanzani's beautiful experiments showed that even very perishable plant or animal infusions do not undergo putrefaction or fermentation when they have been rendered free of animalcules. In the beginning of the nineteenth century, François Appert found that one can preserve foods by enclosing them in airtight containers and heating the containers. He was able in this way to preserve highly perishable foodstuffs indefinitely, and "appertization," as this original canning process was called, came into extensive use for the preservation of foods long before the scientific issue had been finally settled.

In the late eighteenth century, the work of J. Priestley, H. Cavendish, and A. Lavoisier laid the foundations of the chemistry of gases. One of the gases first discovered was oxygen, which soon was recognized to be essential for the life of animals. In the light of this knowledge, it seemed possible that the hermetic sealing recommended by Spallanzani and practiced by Appert was effective in preventing the appearance of microbes and the decomposition of organic matter, not because it excluded air-carrying germs but because it excluded oxygen.

the experiments of Pasteur

By 1860 some scientists had begun to realize that there is a *causal relationship* between the development of microorganisms in organic infusions and the chemical changes that take place in these infusions: *microorganisms are the agents that bring about the chemical changes.* The great pioneer in these studies was Louis Pasteur (Figure 1.3). However, the acceptance of this concept was conditional on the demonstration that spontaneous generation does not occur. Stung by the continued claims of adherents to the doctrine of spontaneous generation, Pasteur finally initiated a series of experiments that effectively ended the controversy.

Figure 1.3
Louis Pasteur (1822–1895). Courtesy of the Institut Pasteur, Paris.

Pasteur first demonstrated that air does contain microscopically observable organisms. He aspirated large quantities of air through a tube that contained a plug of guncotton, which served as a filter. The plug was then dissolved and the sediment examined microscopically. The sediment contained considerable numbers of small round or oval bodies, indistinguishable from microorganisms. Pasteur next confirmed the fact that heated air can be supplied to a boiled infusion without giving rise to microbial development. He went on to show that the addition of a piece of germ-laden guncotton to a sterile infusion invariably provoked microbial growth. These experiments showed Pasteur how germs can enter infusions and led him to what was perhaps his most elegant experiment on the subject. This was the demonstration that infusions will remain sterile indefinitely in open flasks, provided that the neck of the flask is drawn out and bent down in such a way that the germs from the air cannot ascend it. Pasteur's swan-necked flask is illustrated in Figure 1.4. If the neck of such a flask was broken off, the infusion

Figure 1.4
The swan-necked flask used by Pasteur during his studies on spontaneous generation. The construction of the neck permitted free access of air to the flask contents but prevented entry of microorganisms present in the air.