BASIC BACTERIOLOGY

Its Biological and Chemical Background

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Preface

As with the first edition, this book attempts to present the problems confronting bacteriologists. It is evident that the worker in bacteriology uses the principles of physics, chemistry, and biology if he is competent in his own area of specialization. Thus a need exists for a specialized treatment of these sciences oriented for the student of bacteriology. This need serves as our justification for our treatment of many fundamental physical, chemical, and biological problems in a bacteriology text.

Inasmuch as a large number of textbooks are available at the elementary level and numerous monographs and reviews have been written at the most advanced level, we have sought to bridge the gap between these two sources of information. Therefore, our treatment has been aimed at producing a work of intermediate complexity. It is assumed that the reader has mastered the basic vocabulary of biology and chemistry and has already had some experience in the laboratory with the technics and materials of bacteriology.

Certain lacunae exist in the source books used by students. In an attempt to fill these we have introduced subject matter new to textbooks of bacteriology and treated certain traditional matters with a different emphasis than exists in the popular texts. In the light of this third objective we have no desire to duplicate satisfactory texts but rather hope to supplement and round out the treatments already in existence. In the discussion of unsettled matters we have tried to present a statement of the facts and have not hesitated to state our own opinion or to inject new, even if unpopular, ideas. We do hope to identify for the reader what is fact and what is opinion so that he may perceive unsettled problems and make his own judgments.

There is an ever-present failure in education to stress the necessity for some grasp of the over-all significance of general ideas in order that fundamental principles may be employed in achieving an understanding of diverse topics. Consequently, in the earlier chapters a certain amount of "elementary" but basic material is included in order to provide a fully integrated picture of the subject under discussion. To help the reader integrate ideas we have included simple things at various points and attempted to develop from these elementary concepts the more complex ideas present in the same or later chapters. We have attempted to explain bacteriological phenomena rather than merely to state their occurrence.

Few compendia of data are presented, and we hope to have succeeded in emphasizing ideas and principles rather than factual knowledge. Specific facts are introduced only as they make a contribution to the development of knowledge of principles and as they may be employed to illustrate established principles. In general, the use of graphic illustrations has been favored rather than tabulated data.

It is also our hope to communicate some insight into the nature of the general methodology of science. For this reason we have injected a measure of scientific philosophy into various portions of the work and have criticized some of the approaches, methods, and data of bacteriology. In such cases we have chosen situations which seemed particularly suitable for the purpose and within the limits of our personal competence.

We believe that the science of bacteriology has matured to the extent that a textbook need not be cluttered with references. In other sciences it has been generally appreciated that certain principles and data exist which are accepted by all serious investigators and that it serves no essential purpose in these fields to refer the student to the original literature. We have adopted this attitude for the areas of bacteriology considered. On the other hand, we must admit that the situation in bacteriology is more fluid than in some of the older sciences; therefore, we have not entirely abandoned reference to the original literature. In order to avoid interruptions of the flow of thought occasioned by the inclusion of any large number of references within the body of the textual material, we have listed selected references and review articles at the end of each chapter as a guide for further reading. Papers outside the bacteriological journals which may be useful to the bacteriologist have been included.

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Contents

CHAPTER I

The Scope of Bacteriology

Bacteriology is, of course, the study of particular kinds of microorganisms, the bacteria. This science embraces mankind's knowledge of particular kinds of living organisms. As such it is but one aspect of man's curiosity about the universe of living organisms and only one subdivision of the science of biology. Scientific knowledge is the accumulation of data about the universe, gained and verified by observation and experiment, and reduced by means of ordered and logical thinking to laws of nature descriptive of the relations of things and events. Bacteriology as a pure science is concerned with the study of the morphology, physiology, and taxonomy of particular microorganisms and their occurrence, variation, heredity, and evolution. It includes the integration of knowledge of physics, chemistry, and general biology with a particular aspect of biology, and on occasion is the vehicle by means of which some general biochemical or biological relation is discovered or verified.

It is in the nature of science that in its infancy it can only be concerned with objects obvious to man in his natural environment. It is only as instrumentation develops and extends man's senses beyond the immediately perceived, that science can concern itself with the less apparent objects and events of nature and the more subtle relations existent between things. Inevitably, this evolution in study has meant that bacteriology developed as a science long after scientific study of other organisms had begun. It has also meant that the original students of bacteriological phenomena received their training in other sciences. This breadth of experience reflected to the immense benefit of bacteriology, since investigators could make unusually rapid progress in extending knowledge of general applicability from other fields to bacteriology. It has also resulted in the fact that bacteriology never has had a tradition of conservatism in the extension, practical application, and adaptation of the technics and theoretical knowledge of other sciences. In addition, bacteria present certain unique advantages for study because they grow rapidly and large numbers are readily available. Therefore, bacteria have been and are becoming increasingly important as tools for investigations in many different sciences.

But if the nature of the historical development of bacteriology has had advantages sometimes denied in degree to other sciences, it has also had its disadvantages. The chief of these has been a relative lack of creative interest in bacteria as such. There has not been a great pool of scientific personnel studying bacteria because of an intrinsic interest in the bacteria. Thus, as the applications of bacteriological knowledge became evident, and they became evident early in the history of the science, major emphasis shifted to applied bacteriology. A person often was trained as, and felt himself to be, not a bacteriologist so much as a medical bacteriologist, dairy bacteriologist, soil bacteriologist, etc.

The increasing awareness of the singular virtues of bacteria as tools for the study of many problems of biology, particularly metabolism, at both the cellular and subcellular levels has attracted an increasing army of investigators. In this enthusiasm there is a tendency to exploit bacteria without a balanced growth in the knowledge of bacteria as bacteria. The construction of generalizations bridging the apparent gaps between the sciences is both a noble and a necessary activity. But it should not be denied that the importance of the bridge rests on the separate existence of islands to be connected. The foundations of a generalization that attempts to span wide areas of knowledge are only as secure as the factual knowledge of the individual sciences upon which they rest.

The study of pure bacteriology is motivated by the desire to understand the nature of bacteria and their place in the scheme of the universe. Practical bacteriology seeks to control the harmful activities of bacteria and direct their useful activities. The line between applied and pure bacteriology is tenuous, and no universal agreement can be expected as to where it should be drawn. Nor would any great purpose be served by any strict definition of the difference between the two phases of the science. But it is useful to recognize that progress in any science, including bacteriology, and its practical utility for society, is most rapid when there is some balance of effort expended on both practical phases and the esoteric or academic studies. Each category of investigation feeds the other. Applied science often helps in the discovery or more precise definition of phenomena. It makes possible the creation of the material means and leisure time that society can invest in the pursuit of pure science for its intellectual satisfactions. Pure science provides the rational basis for practice and suggests new applications. When technology becomes more than merely empirical in methods and outlook, it is because pure science has provided a firm foundation of factual data and theoretical concepts which practicing engineers, technologists, and physicians have mastered.

The science of biology can be divided into subsciences by a number of means. The generic system which separates bacteriology as a discipline is the logical outcome of one of the historical trends in the development of biology. It is inherent in the nature of biological studies that individual students of life will tend to concentrate their studies upon particular and phylogenetically related organisms.

The recognition of living forms invisible to the unaided eye was a dramatic experience in the intellectual history of mankind. So it is no wonder that a word, *microbe*, was invented (1878) to describe these apparently related organisms. Eventually the concept of microbiology developed as a separate science. But microbes form a large group of very diverse organisms, so that their study is actually the task of scientists who properly call themselves virologists, bacteriologists, mycologists, algologists, protozoologists, helminthologists, etc. The diversity of forms termed microbes has meant that in recent times few persons, if any, have mastered the essential components of all the sciences that can be cataloged under the heading of microbiology. The technics used to study bacteria have had wide application in the study of other microbes, so that there is possibly more in common between the technics of the microbiological sciences than between the phylogeny of the organisms studied. Thus the definition of microbiology as a science might be said to have an operational basis rather than a phylogenetic one. In any case, the lexicographer, if not always those calling themselves microbiologists, has recognized the limitations so that a popular dictionary notes that the term microbiology as generally employed is synonymous with bacteriology. In this sense the use of the term bacteriology is to be preferred.

If a generic concept is to be used in defining the sub-branches of biology there is no compelling logic in considering microbiology as a distinct science. Certainly there is no reason more important than those which have prevented anyone from volunteering to father the sibling science, the monstrosity which would be labeled *macrobiology*. The use of common technics, the discovery of general laws provided the stimulus for thinking in terms of a unified science and the invention of the concept of a science of microbiology. But this term, generic in its implications, violates the logic of a generic system of separation of the biological sciences. Yet the boundaries between organisms must be crossed and identified. For this purpose it would seem better to think in terms of sciences of systematics such as comparative cytology, comparative physiology, and comparative biochemistry. This latter cataloging is also more truly descriptive of the actual situation of the social organization of the sciences. It permits the use of restricted labels with more scientific meaning than the term microbiology. And also important, because science is an agency in the hands of men, its use would help preserve scientific modesty. The true scientist foreswears the use of pretentious labels and aims for an accurate description of his interests and competence. It is sufficient for the bacteriologist to be called a bacteriologist and nothing more.

The efforts of bacteriologists may be conveniently listed as occurring in five areas of activity:

1. *General or pure bacteriology.* This field would include the studies devoted to understanding the fundamental nature of bacteria and their relations to one another and to other organisms.

2. *Soil bacteriology.* Studies in this field have contributed particularly toward understanding of the problem of the fertility of soil and the natural mechanisms for the cyclic biological utilization and deposition of elements in soil and large bodies of water.

3. *Medical bacteriology.*
    - A. Animal pathology
        - human
        - veterinary
    - B. Plant pathology
    - C. Public health science
    - D. Sanitary engineering

4. *Food technology.*
    - A. Dairy
        - manufacture
        - control
    - B. Control
        - canning industry
        - other preservation industries
            - refrigeration
            - hypertonic solutions
                - sugar
                - salts
            - chemical
                - acid
                - spices
    - C. Fermented food products: alcoholic beverages, vinegar, pickles, sauerkraut, silage.
    - D. Microorganisms as sources of nutrients: protein, fat, and vitamins.

5. *Industrial bacteriology.*
    - A. Industrial chemical or fermentation technology
        1. Production of chemicals: enzymes, antibiotics, vitamins, hormones, industrial solvents (acetone, glycerol, glycols, and ethyl, butyl, and isopropyl alcohols), organic acids (acetic, citric, lactic, gluconic).
        2. Microbiological treatment of industrial products: tanning of leather, retting of hemp, curing of tobacco, coagulation of latex, disposal of industrial wastes.

B. Control of nuisances of bacterial origin such as acceleration of galvanic corrosion, plugging of oil wells and of pipes in the food industry and in irrigation systems, deterioration of rubber.

Bacteria have been considered or employed in many areas of science. These efforts may be conveniently listed and illustrated as follows:

1. *General problems of biology.* The development of bacteriology made possible the definitive overthrow of the theory of spontaneous generation, an event of major philosophic import in the history of biology. Discussions of the origin, nature, and evolutionary development of protoplasm inevitably draw upon bacteriological knowledge.

2. *Physiology.* Bacteria are being increasingly employed as tools for the solution of fundamental problems in genetics, cellular physiology, and comparative biochemistry. Progress in the study of intermediary metabolism has been particularly advanced by the study of metabolic systems of bacteria. Much work remains to be done on the contributions both useful and harmful made by the indigenous bacterial flora to the economy of multicellular organisms. One intriguing approach to these problems has been the rearing of multicellular organisms in germ-free environments. There is an increasing awareness of the existence of unexpected roles for bacteria in the noninfectious disease picture of animals. The as yet incomplete evidence for a role for intestinal bacteria and their endotoxins as immediate causal agents of death in hemorrhagic shock may be cited as an example. Another is the occurrence of urease, an enzyme believed limited to the plant kingdom but found in the stomach and intestine of man. This enzyme is a product of the bacterial flora of the alimentary tract and can be a contributing cause of death in liver failure, a condition that is accompanied by an inability to dispose of ammonia derived from the activity of urease. The urease acts on urea excreted into the alimentary tract.

3. *Chemistry.* Besides helping pose many questions with which chemistry must concern itself, bacteria have had important uses in analytical chemistry. Employing bacteria, many sensitive and specific methods have been developed for the analysis of carbohydrates, amino acids, and vitamins and in establishing the positions of radioactive isotopes in labeled metabolic compounds. It is probable that bacteria will find uses in analyses for trace elements and sterols. Bacteria have also been used in the separation and synthesis of optical isomers. In organic synthesis, bacteria have been employed in introducing substituent groups into molecules, for example, in the synthesis of synthetic sterols, when more conventional chemical methods fail or are technically difficult.

4. *Geology.* Bacteria have been used for the detection of petroleum deposits. In addition, the possibility that bacteria are involved in the formation of petroleum is being actively studied. Bacteria have been considered,