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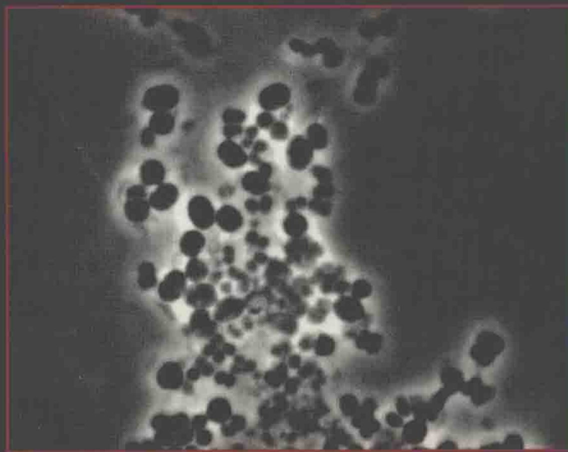
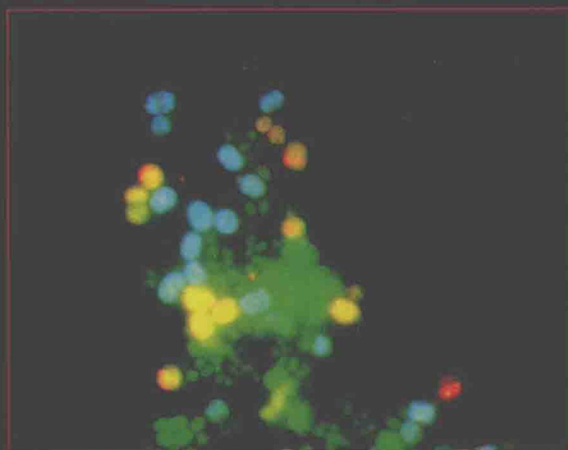
BROCK BIOLOGY OF MICROORGANISMS





TENTH EDITION

MICHAEL T. MADIGAN
JOHN M. MARTINKO
JACK PARKER

Tenth Edition

BROCK

BIOLOGY OF MICROORGANISMS

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John M. Martinko
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Southern Illinois University Carbondale

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BROCK BIOLOGY OF MICROORGANISMS

New Organization

The Tenth Edition is completely reorganized into six units that group chapters together within a major theme, allowing you to easily relate thematic coverage to core materials and to the goals of your course. This edition also features seven new chapters

NEW! Unit I forms the heart of the general microbiology course as envisioned by the Education Division of the ASM.

NEW! Chapter 2 provides an **early overview of microbial diversity.**

Chapter 9 emphasizes the **core concepts of virology.** (Chapter 16 explores viral diversity in more detail.)

Chapter 10 was rewritten to better reflect **bacterial genetics as it is actually practiced today**—a blend of in vivo and in vitro science.

NEW! Chapter 15 covers the essentials of the **microbial genomics projects**, from bacteria to yeast.

NEW! Chapter 16 allows instructors to easily choose those **viral examples** they wish to emphasize as a supplement to the essentials material in Chapter 9.

NEW! Chapter 18 emphasizes **methods**.

I. PRINCIPLES OF MICROBIOLOGY

1. Microorganisms and Microbiology
2. An Overview of Microbial Life
3. Macromolecules
4. Cell Structure/Function
5. Nutrition, Laboratory Culture, and Metabolism of Microorganisms
6. Microbial Growth
7. Principles of Microbial Molecular Biology
8. Regulation of Gene Expression
9. Essentials of Virology
10. Bacterial Genetics

II. EVOLUTIONARY MICROBIOLOGY AND MICROBIAL DIVERSITY

11. Microbial Evolution and Systematics
12. Prokaryotic Diversity: *Bacteria*
13. Prokaryotic Diversity: The *Archaea*
14. Eukaryotic Cell Biology and Eukaryotic Microorganisms
15. Microbial Genomics
16. Bacterial, Plant, and Animal Viruses

III. METABOLIC DIVERSITY AND MICROBIAL ECOLOGY

17. Metabolic Diversity
18. Methods in Microbial Ecology
19. Microbial Habitats, Nutrient Cycles, and Interactions with Plants and Animals

IV. IMMUNOLOGY, PATHOGENICITY, AND HOST RESPONSES

20. Microbial Growth Control
21. Human–Microbe Interactions
22. Essentials of Immunology
23. Molecular Immunology
24. Clinical Microbiology and Immunology

V. MICROBIAL DISEASES

25. Epidemiology
26. Person-to-Person Microbial Diseases
27. Animal-Transmitted, Arthropod-Transmitted, and Soilborne Microbial Diseases
28. Wastewater Treatment, Water Purification, and Waterborne Microbial Diseases
29. Food Preservation and Foodborne Microbial Diseases

VI. MICROORGANISMS AS TOOLS FOR INDUSTRY AND RESEARCH

30. Industrial Microbiology/Biocatalysis
31. Genetic Engineering and Biotechnology

Chapter 19 covers **habitats and microbial ecology** without including material on methods.

NEW! **Two new chapters on immunology**: Chapter 22 covers the essentials and Chapter 23 covers the molecular details.

Chapter 24 includes expanded coverage of **immunoassays**.

Coverage of **diseases** now spans five chapters instead of two.

NEW! Three new chapters on these important topics in microbiology.

Chapters 30 and 31 have been grouped into their own unit to better reflect their common goals and contrast their industrial production methods.

Section Numbers keyed to page numbers provides easy reference points.

New "Superheads" more effectively organize chapter contents.

The working glossary is the students' guide to the language of microbiology. Understanding these terms is key to mastery of the concepts in the chapter.


To study microorganisms in the laboratory, it is usually necessary to culture (grow) them. This can be done in a number of ways, including the use of solid culture media and the Petri plate, as shown here. Individual cells that were spread out on the plate grow and divide to form *colonies*. Although some common nutritional principles apply to all organisms, many microorganisms have special nutritional and cultural requirements. In addition, in order to sustain life processes, all microorganisms must carry out one or more series of reactions that conserve energy. Thus, an understanding of nutrition and bioenergetics is necessary to understand how microbial cells "make a living" in their natural habitats.

NUTRITION, LABORATORY CULTURE, AND METABOLISM OF MICROORGANISMS

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WORKING GLOSSARY

Activation energy the energy required to bring substrates to the reactive state

Aerobe a microorganism able to use O_2 in respiration

Anabolism the sum total of all biosynthetic reactions in the cell

Anaerobe a microorganism that either can or must grow in the absence of O_2

Aseptic technique the series of manipulations used to prevent contamination during the handling of sterile objects or microbial cultures

ATP synthase (ATPase) A multiprotein enzyme complex embedded in the membrane that catalyzes the synthesis of ATP coupled to dissipation of the proton motive force

Autotroph an organism capable of biosynthesizing all cell material from CO_2 as the

Coenzyme a small nonprotein molecule that participates in a catalytic reaction as part of an enzyme

Complex medium a culture medium composed of digests of chemically undefined substances such as yeast and meat extracts

Culture medium an aqueous solution of various nutrients suitable for the growth of microorganisms

Defined medium a culture medium whose precise chemical composition is known

Electron acceptor a substance that can accept electrons from some other substance, thereby becoming reduced in the process

Electron donor a substance that can donate electrons to some electron acceptor, thereby becoming oxidized in the process

glucose is fermented yielding energy (ATP) and various fermentation products. Also called the Embden-Meyerhof pathway

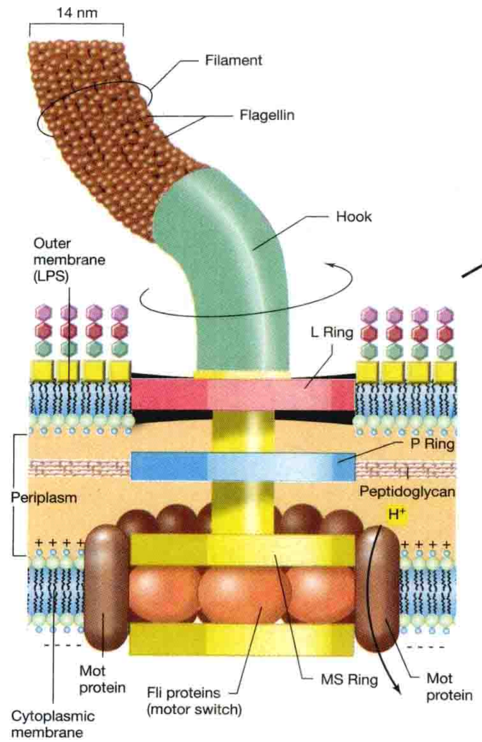
Oxidative phosphorylation the production of ATP at the expense of a proton motive force formed by electron transport

Photophosphorylation the production of ATP from a proton motive force formed from photosynthetic reactions

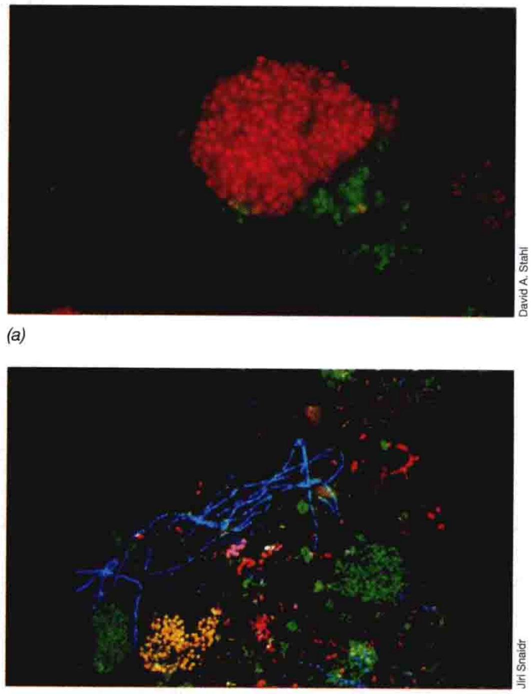
Proton motive force an energized state of the membrane resulting from the separation of charge and the elements of water (H^+ versus OH^-) across the membrane

Pure culture a culture that contains a single kind of microorganism

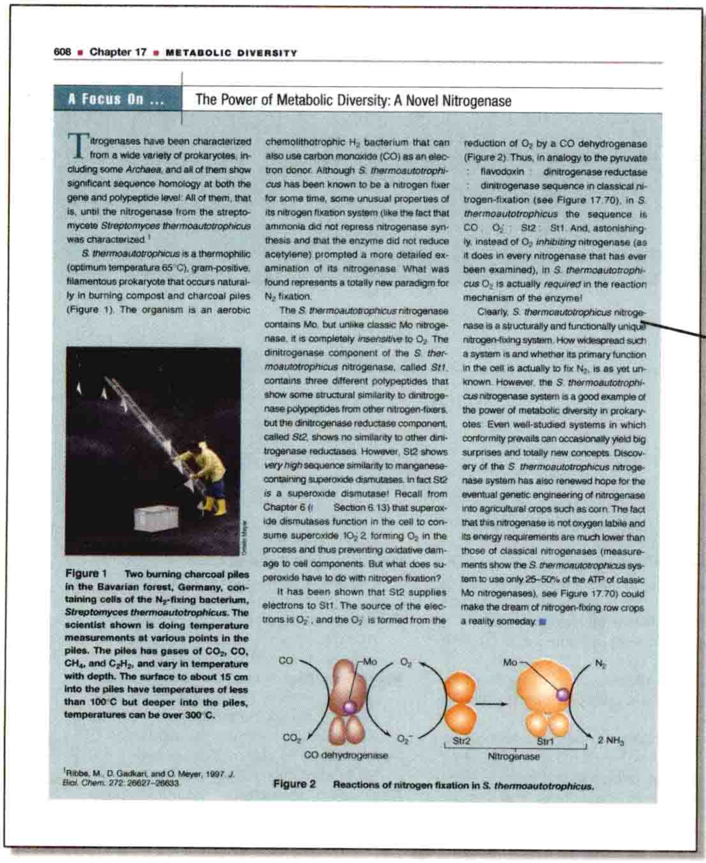
Reduction potential the inherent tendency (measured in volts) of a compound to donate electrons; E_0' is reduction...



The exceptional art program has been thoroughly reviewed and adjusted to maximize its impact and clarity.



Outstanding micrographs, most obtained from researchers in the field.



608 ■ Chapter 17 ■ METABOLIC DIVERSITY

A Focus On ... The Power of Metabolic Diversity: A Novel Nitrogenase

Nitrogenases have been characterized from a wide variety of prokaryotes, including some *Archaea*, and all of them show significant sequence homology at both the gene and polypeptide level: All of them, that is, until the nitrogenase from the streptomycete *Streptomyces thermoautotrophicus* was characterized.[1]

S. thermoautotrophicus is a thermophilic (optimum temperature 65°C), gram-positive, filamentous prokaryote that occurs naturally in burning compost and charcoal piles (Figure 1). The organism is an aerobic chemolithotrophic H_2 bacterium that can also use carbon monoxide (CO) as an electron donor. Although *S. thermoautotrophicus* has been known to be a nitrogen fixer for some time, some unusual properties of its nitrogen fixation system (like the fact that ammonia did not repress nitrogenase synthesis and that the enzyme did not reduce acetylene) prompted a more detailed examination of its nitrogenase. What was found represents a totally new paradigm for N_2 fixation.

The *S. thermoautotrophicus* nitrogenase contains Mo, but unlike classic Mo nitrogenase, it is completely *insensitive* to O_2. The dinitrogenase component of the *S. thermoautotrophicus* nitrogenase, called *St1*, contains three different polypeptides that show some structural similarity to dinitrogenase polypeptides from other nitrogen-fixers, but the dinitrogenase reductase component, called *St2*, shows no similarity to other dinitrogenase reductases. However, St2 shows *very high* sequence similarity to manganese-containing superoxide dismutases. In fact St2 *is* a superoxide dismutase! Recall from Chapter 6 (Section 6.13) that superoxide dismutases function in the cell to consume superoxide (O_2^-), forming O_2 in the process and thus preventing oxidative damage to cell components. But what does superoxide have to do with nitrogen fixation?

It has been shown that St2 supplies electrons to St1. The source of the electrons is O_2^-, and the O_2^- is formed from the reduction of O_2 by a CO dehydrogenase (Figure 2). Thus, in analogy to the pyruvate : flavodoxin : dinitrogenase reductase : dinitrogenase sequence in classical nitrogen-fixation (see Figure 17.70), in *S. thermoautotrophicus* the sequence is CO : O_2^- : St2 : St1. And, astonishingly, instead of O_2 *inhibiting* nitrogenase (as it does in every nitrogenase that has ever been examined), in *S. thermoautotrophicus* O_2 is actually *required* in the reaction mechanism of the enzyme!

Clearly, *S. thermoautotrophicus* nitrogenase is a structurally and functionally unique nitrogen-fixing system. How widespread such a system is and whether its primary function in the cell is actually to fix N_2, is as yet unknown. However, the *S. thermoautotrophicus* nitrogenase system is a good example of the power of metabolic diversity in prokaryotes. Even well-studied systems in which conformity prevails can occasionally yield big surprises and totally new concepts. Discovery of the *S. thermoautotrophicus* nitrogenase system has also renewed hope for the eventual genetic engineering of nitrogenase into agricultural crops such as corn. The fact that this nitrogenase is not oxygen labile and its energy requirements are much lower than those of classical nitrogenases (measurements show the *S. thermoautotrophicus* system to use only 25–50% of the ATP of classic Mo nitrogenases), see Figure 17.70) could make the dream of nitrogen-fixing row crops a reality someday. ■

Figure 1 **Two burning charcoal piles in the Bavarian forest, Germany, containing cells of the N_2-fixing bacterium, *Streptomyces thermoautotrophicus*. The scientist shown is doing temperature measurements at various points in the piles. The piles has gases of CO_2, CO, CH_4, and C_2H_2, and vary in temperature with depth. The surface to about 15 cm into the piles have temperatures of less than 100°C but deeper into the piles, temperatures can be over 300°C.**

CO, Mo, O_2, Mo, N_2, CO_2, O_2^-, Str2, Str1, 2 NH_3, CO dehydrogenase, Nitrogenase

Figure 2 **Reactions of nitrogen fixation in *S. thermoautotrophicus*.**

[1]Ribbe, M., D. Gadkari, and O. Meyer, 1997. *J. Biol. Chem.* 272: 26627–26633.

Interesting scientific asides in boxed inserts—Techniques and Application boxes describe methods in microbiology and their application in the real world; Learning from the Past boxes describe historical developments in microbiology and their implications today; A Focus On boxes address text topics in greater detail.

Completely redesigned graphs facilitate student comprehension.

152 ■ Chapter 6 ■ **MICROBIAL GROWTH**

The maximum growth temperature of a given organism most likely reflects the inactivation of one or more key proteins in the cell. However, the factors controlling an organism's *minimum* growth temperature are not as clear. As mentioned earlier (Section 4.5), the cytoplasmic membrane must be in a fluid state for proper functioning. Perhaps the minimum temperature of an organism results from "freezing" of the cytoplasmic membrane so it no longer functions properly in nutrient transport or proton gradient formation. This explanation is supported by experiments in which the minimum temperature for an organism is altered to some extent by adjustments in membrane lipid composition (see Section 6.9). It is also observed that the cardinal temperatures of different microorganisms differ widely; some organisms have temperature optima as low as 4°C and some higher than 100°C. The temperature range throughout which growth occurs is even wider than this, from below freezing to greater than boiling. (The archaeon *Pyrolobus fumarii* has a temperature maximum of 113°C!) However, no single organism can grow over this whole temperature range, and the typical range for a given organism is about 30°, although some have a broader temperature range than others.

Temperature Classes of Organisms

Although there is a continuum of organisms, from those with very low temperature optima to those with high temperature optima, it is possible to broadly distinguish *four groups* of microorganisms in relation to their temperature optima: **psychrophiles**, with low temperature optima, **mesophiles**, with midrange temperature optima, **thermophiles**, with high temperature optima, and **hyperthermophiles**, with very high temperature optima (Figure 6.17). Mesophiles are found in warm-blooded animals and in terrestrial and aquatic environments in temperate and tropical latitudes. Psychrophiles and thermophiles are found in unusually cold and unusually hot environments, respectively. Hyperthermophiles are found in extremely hot habitats such as hot springs, geysers, and deep-sea hydrothermal vents (see Sections 6.10 and 19.8).

In *Escherichia coli*, a typical mesophile, a detailed study of growth as a function of temperature has precisely defined its cardinal temperatures. The optimum temperature of *E. coli* in a complex medium is 39°C, the maximum is 48°C, and the minimum is 8°C. These values are subject to slight strain differences, and in general, the maximum and minimum temperatures supporting growth of an organism are higher and lower, respectively, when tested in complex rather than defined media.

✓ 6.8 Concept Check

Temperature is a major environmental factor controlling microbial growth. The cardinal temperatures describe the minimum, optimum, and maximum temperatures at which each organism grows. Microorganisms can be grouped by the temperature ranges they require.

- ✓ What are the approximate cardinal temperatures for *Escherichia coli?* To what temperature class does it belong?
- ✓ How does a *hyperthermophile* differ from a *psychrophile?*
- ✓ *Escherichia coli* can grow at a higher temperature in complex than in defined medium. Why?

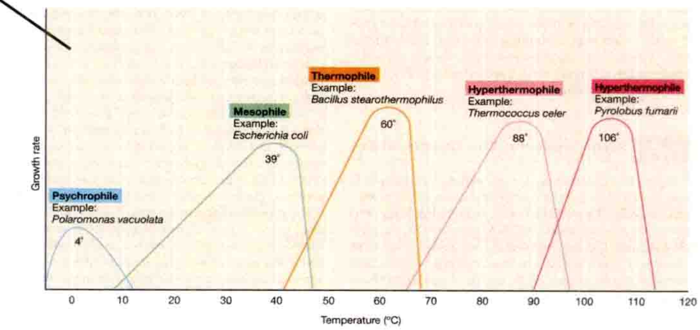


Figure 6.17 Relation of temperature to growth rates of a typical psychrophile, a typical mesophile, a typical thermophile, and two different hyperthermophiles. The temperature optima of the example organisms are shown on the graph.

Concept Checks summarize each section and provide quiz questions so students can evaluate their understanding as they progress through the chapter.

✓ 6.8 Concept Check

Temperature is a major environmental factor controlling microbial growth. The cardinal temperatures describe the minimum, optimum, and maximum temperatures at which each organism grows. Microorganisms can be grouped by the temperature ranges they require.

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called **exons**, and the intervening noncoding regions, **introns**. Both intron and exon regions are transcribed into the **primary transcript**, or **pre-mRNA**, and the functional mRNA is subsequently formed by removal of noncoding regions. A summary contrasting genetic phenomena in prokaryotes and eukaryotes is given in Figure 7.2.

✓ 7.1 Concept Check

The three key processes of macromolecular synthesis are DNA replication; transcription, the synthesis of RNA from a DNA template; and translation, the synthesis of proteins using messenger RNA as template. Although the basic processes are the same in both prokaryotes and eukaryotes, the organization of genetic information is more complex in eukaryotes. Many eukaryotic genes have both coding regions (exons) and noncoding regions (introns).

- ✓ What three informational macromolecules are involved in genetic information flow?
- ✓ In all cells there are three processes involved in genetic information flow. What are they?

II DNA STRUCTURE

We dealt with the general structure of nucleic acids in Chapter 3. In the next few sections of this chapter we shall discuss the details of DNA structure necessary for an understanding of molecular genetics and the types of genetic elements containing DNA that are found in cells. With this information as a basis, we can then discuss how DNA is replicated, transcribed into RNA, and translated into protein.

7.2 DNA Structure: The Double Helix

The genetic information for all cellular processes is stored in DNA in the *sequence* of bases along the polynucleotide chain. As we have noted, only four different nucleic acid bases are found in DNA: adenine (A), guanine (G), cytosine (C), and thymine (T). As already shown in Figure 3.11, the backbone of the DNA chain consists of alternating units of phosphate and the sugar *deoxyribose*; connected to each sugar is one of the nucleic acid *bases*. Recall especially the numbering system for the positions of sugar and base; the phosphate connecting two sugars spans from the 3′-carbon of one sugar to the 5′-carbon of the adjacent sugar (see Figure 7.14). At one end of the DNA molecule the sugar has a phosphate on the 5′-hydroxyl, whereas at the other end the sugar has a free hydroxyl at the 3′-position.

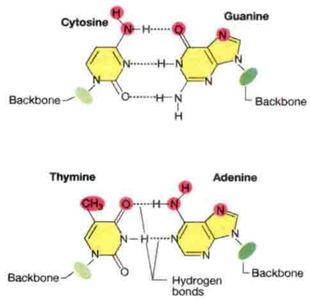

Figure 7.3 Specific pairing between adenine (A) and thymine (T) and between guanine (G) and cytosine (C) via hydrogen bonds. These two base pairs are the base pairs typically found in double-stranded DNA. Atoms that are found in the major groove of the double helix and that interact with proteins are highlighted in red. The deoxyribose phosphate backbones of the two strands of DNA are also indicated.

DNA as a Double Helix

As we will discuss in Chapter 9, the chromosomes of some viruses are single-stranded. In all **cellular organism chromosomes**, however, DNA exists as two polynucleotide strands whose base sequences are **complementary**. The complementarity of DNA arises because of the specific pairing of the purine and pyrimidine bases: Adenine always pairs with thymine, and guanine always pairs with cytosine (Figure 7.3). The two strands in the resulting **double-stranded** molecule are arranged in an *antiparallel* fashion (see Figure 7.4). This means the two strands are in a "head-to-toe" arrangement. In Figure 7.4 the strand on the left is arranged 5′ to 3′ top to bottom, whereas the other strand is 5′ to 3′ bottom to top. The two strands are wrapped around each other forming a **double helix** (Figure 7.5). In this double helix, DNA forms two distinct grooves, the *major groove* and the *minor groove*. Of the many proteins that interact specifically with DNA (as we shall see in Chapter 8), most engage predominantly with the major groove, where there is a considerable amount of space. Because of the regularity of the double helix, some atoms of the bases are always exposed in the major groove (and some in the minor groove). Atoms in the major groove that are known to be important in interactions with proteins are shown in Figure 7.3.

The size of a DNA molecule can be expressed in terms of its *molecular weight*, but because a single nucleotide has a molecular weight of about 330, and because DNA molecules are many nucleotides long, the molecular weight mounts up rapidly. (The nucleic acid in

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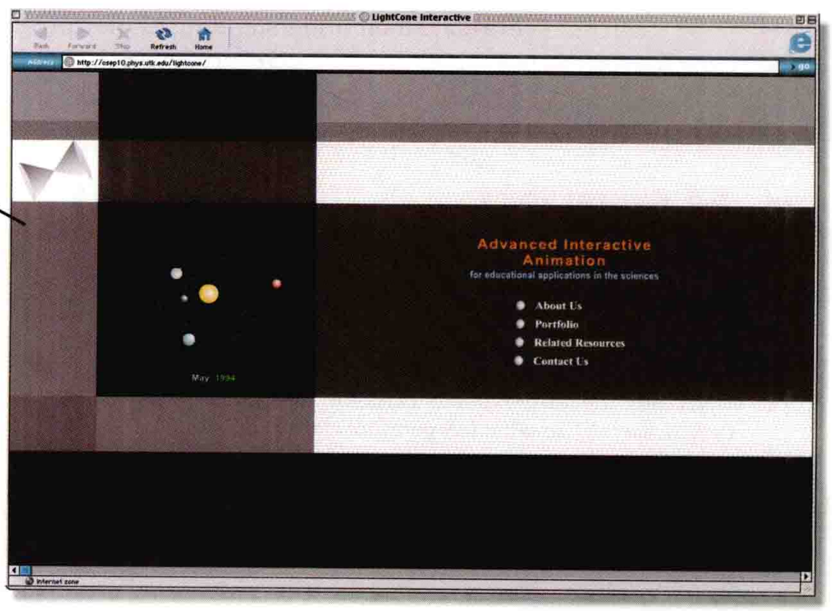

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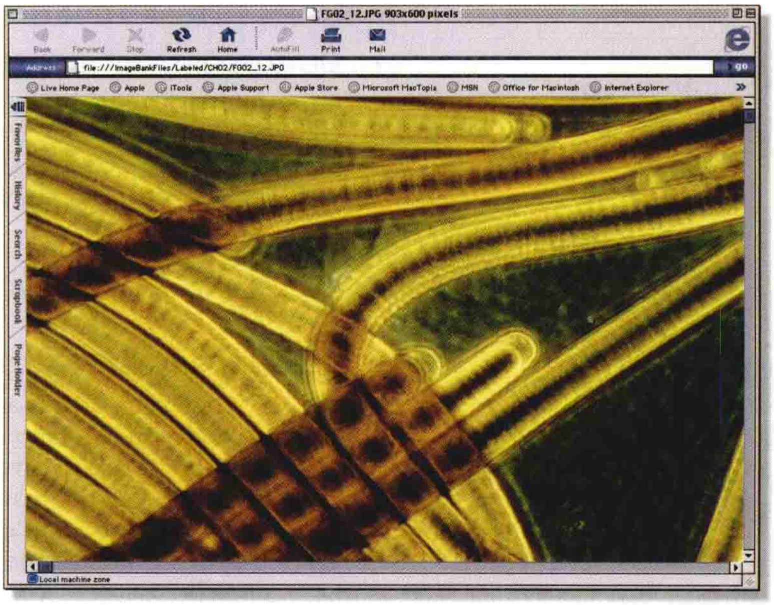

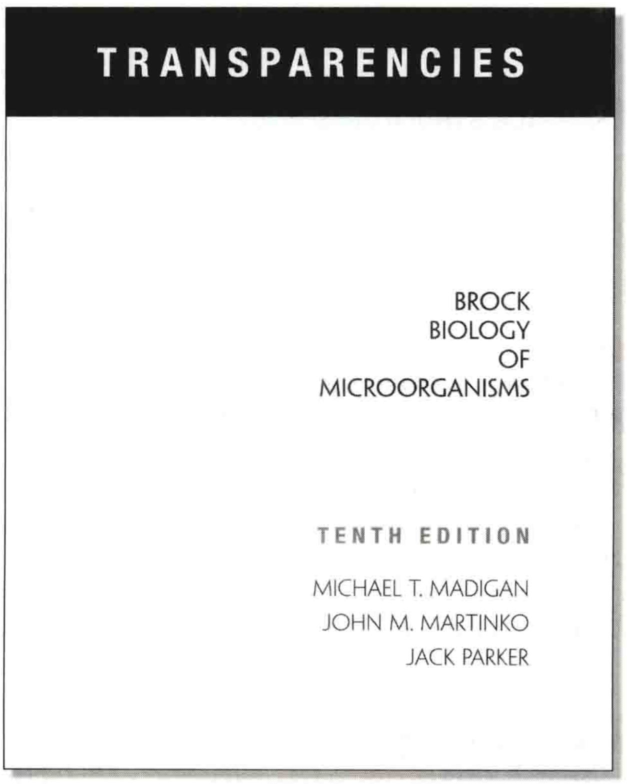

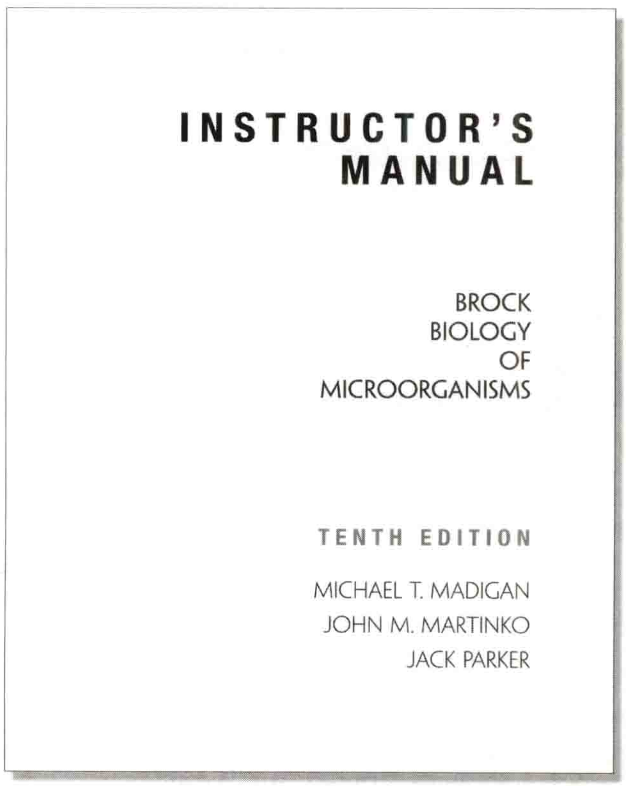

Preface

Microbiology is a biological science that has effectively wedded the old and the new. Some of the basic techniques of microbiology discovered over 100 years ago—the isolation of pure cultures, for example—are still practiced with regularity in the laboratory today. But today's microbiologists are also armed with sophisticated tools that facilitate detailed molecular analyses of microbial cells. These tools have fueled new discoveries that are thrusting microbiology into the limelight of disciplines as diverse as medicine, agriculture, and ecology. It is within this exciting period in microbiology that we present the tenth edition of *Brock Biology of Microorganisms (BBOM)*, a textbook of microbiology that blends fundamental principles (the old) with state-of-the-art science (the new) in a format that will appeal to both students and instructors.

What's New?

Organization

This edition of *BBOM* contains many new organizational features that will help students better master the material and help instructors prepare stimulating presentations for the classroom. First, the book has been extensively reorganized into six major units: (1) Principles of Microbiology; (2) Evolutionary Microbiology and Microbial Diversity; (3) Metabolic Diversity and Microbial Ecology; (4) Immunology, Pathogenicity, and Host Responses; (5) Microbial Diseases; and (6) Microorganisms as Tools for Industry and Research. Each unit consists of several chapters whose content define the themes. Unit 1, The Principles, forms the heart of the general microbiology course as currently envisioned by the Education Division of the American Society for Microbiology (ASM); in other words, Unit 1 is the "core" material that every student should know. Included for the first time in this unit is an overview chapter (Chapter 2) on microbial diversity that introduces the major groups of microorganisms and their evolutionary relationships. This chapter will allow instructors who emphasize the medical or molecular aspects of microbiology the opportunity to give their students a taste of microbial diversity without the details. This chapter also covers some of the basic aspects of cell structure/function and is written in such a way that only a minimal background in chemistry and biology is necessary to follow the story.

Other chapters that have been revamped in Unit 1 include Chapters 9 and 10. Compared with previous editions of *BBOM*, Chapter 9 (Essentials of Virology) has been restructured and downsized to place emphasis on the *essential concepts* of virology, instead of viral diversity. The latter material still exists, however, in the new Chapter 16 (Bacterial, Plant and Animal Viruses), for those instructors who wish to explore viral diversity in more detail. Another substantially reorganized chapter is Chapter 10, Bacterial Genetics. This chapter has been rewritten from two major standpoints, microbial genetics as it occurs in the intact organism (*in vivo)* and microbial genetics as it is practiced *in vitro*. To accomplish the latter, some material from the biotechnology chapter has been reworked and moved to this new chapter on genetics. Thus, Chapter 10 better reflects bacterial genetics as it is actually practiced today—a blend of *in vivo* and *in vitro* science.

As has been a tradition with *BBOM*, the material in each chapter is broken into several *numbered heads* to assist instructors in assigning reading material. But in addition, in parallel to the unit concept that pervades organization at the level of the entire book, the numbered heads within a chapter are themselves grouped into major themes. The latter are signaled by red headings set in all caps, and were introduced in this edition to better group related material within a chapter into logical pieces.

In summary then, the tenth edition of *BBOM* is organized to capture and distill the basics while deploying the full story of the science at those points where it will have maximum impact. The authors and publishers are confident that this new format will make *BBOM 10/e* an even stronger resource for students and instructors alike.

Content

Every three years the authors of this book face one major question: how do we add new material and still keep the book within bounds? Longtime users of *BBOM* will immediately recognize that the tenth edition is essentially no longer than the ninth. This feat was accomplished by balancing the needs of the new material with a careful reevaluation of the old. Nothing essential to a fundamental understanding of microbiology has been deleted from *BBOM*; the tenth edition is still a book built on basic principles and strong science. But streamlining of some chapters along with a first-class art program has given the authors the space necessary to paint an up-to-the-minute picture of the science of microbiology in a volume that does not require weight training to lift off the table.

Several *totally new* chapters will be found in *BBOM 10/e*. The new overview of microbial diversity chapter (Chapter 2) and the viral diversity chapter (Chapter 16) have already been mentioned in this regard. Also new to this edition are Chapter 15

(Microbial Genomics); Chapter 18 (Methods in Microbial Ecology); Chapter 22 (Essentials of Immunology); Chapter 23 (Molecular Immunology); Chapter 27 (Animal-Transmitted, Arthropod-Transmitted, and Soilborne Microbial Diseases); Chapter 28 (Wastewater Treatment, Water Purification, and Waterborne Microbial Diseases); and Chapter 29 (Food Preservation and Foodborne Microbial Diseases). All of these areas are "hot topics" in microbiology today and needed increased visibility and expanded coverage. These new chapters should accomplish just that.

The genomic revolution has transformed microbiology into a new science almost overnight. For the first time, scientists can inspect, almost in a routine fashion now, the entire genetic blueprint of a microorganism, and then compare the blueprint with those of other organisms, from viruses to humans. Genomics has revealed the great genetic unity and diversity of living organisms and has opened the door to new advancements in every discipline of biology. And combined with proteomic analyses, scientists can now ask sophisticated questions about *gene expression* in ways never before possible. Chapter 15 in *BBOM 10/e* tells the genomic story, but goes well beyond just listing organisms whose genomes have been sequenced. The chapter explains what genomics is, how the reams of DNA sequence data that are being generated can be used, and what the genomic revolution has revealed thus far in terms of both the genomic and proteomic capacities of key microorganisms.

The new chapters in immunology were written to provide both the basics and the details of this important science. Chapter 22 (Essentials of Immunology) presents the basic principles of immunology without delving into too much detail. This chapter should therefore be a very student-friendly and readily teachable overview of immunology. We reserve the molecular details of immunology for the rather short Chapter 23. This chapter places the essentials material (Chapter 22) within a molecular context for those students and instructors whose background and interests support the study of immunology at this level. In Chapter 24 (Clinical Microbiology and Immunology) we have expanded our coverage of immunoassays to include more information about the basic mechanisms behind precipitation, agglutination, and antibody production. For those instructors who teach immunology only as a diagnostic or investigative tool, we have also included a very short summary of immune principles here. Thus, with the material on immunology organized as it is, the science of immunology can be integrated into introductory microbiology classes at all levels.

The new chapters in medical microbiology are expansions of this material originally covered in only two chapters in previous editions. This has given the authors the opportunity to develop this important material in a more thorough way. And in this day and age where foodborne and waterborne illnesses are major public health problems (even in developed countries), and new threats to health and security, such as bioterroism, are a fact of life, the unit on medical microbiology and immunology will be both a source of basic principles and a reference for keeping up with events in the news.

In summary, long-time users of *BBOM* will find the tenth edition to be the reliable friend they've always known. New users will find it to be the most current, accurate, and complete coverage of microbiology available in a textbook today. Coupled with an excellent set of teaching aids (see below) *BBOM 10/e* should set the standard in the field for years to come.

Pedagogical Aids

Art and photos are the mainstay of any textbook in the biological sciences. And frankly speaking, we think *BBOM 10/e* has the best in the business in both regards. The art program has once again been delivered by Imagineering of Toronto, Canada. Virtually every piece of art has seen some modification in order to maximize its impact and clarity. Some stylistic improvements have also been introduced into the art program, including a beautiful new rendering of all graphs in the book. High quality photos and photomicrographs have been a mainstay in *Biology of Microorganisms* since the first edition appeared in 1970, and *BBOM 10/e* proudly carries on this tradition with the inclusion of nearly 50 new B&W and color photos. And, as usual, these photos have been supplied by top researchers in the field.

BBOM 10/e once again employs a variety of student study aids to weave together the concepts and strengthen the learning experience. Instead of placing summary and quiz material only at the *end* of a chapter (as many textbooks like to do), *BBOM 10/e* contains two review tools—concept checks and concept links—*built right into* each chapter. Each ***Concept Check*** consists of a short summary of the material in the previous numbered head along with a short series of questions that together, reviews the major points in that section. ***Concept Links*** (signaled by the blue link icon,) are the ties between the current text and related material found elsewhere in the book. In addition, readers will find the popular ***Working Glossary***—a dictionary of essential terms—at the opening of each chapter. The Working Glossary is the student's lifeline to the *language* of microbiology, an understanding of which is a key to mastering the concepts. Finally, and as in previous editions, the end of each chapter contains a number of review and application questions, many new to this edition; the questions are designed to probe a student's retention of important concepts and ability to solve problems.

Supplements

A number of supplements accompany this book. Totally new to the tenth edition of *BBOM* are a series of online media tutorials that are found in the ***Companion Website*** (*www.prenhall.com/brock*). These cover a number of conceptually challenging topics in microbiology, including basic processes in molecular biology, genetics, medical microbiology and immunology, and microbial metabolism. These unique instructional resources include animations, interactive exercises, and self-quizzes, and will be a major supporting feature for the material in Unit I of *BBOM 10/e*, the heart of the introductory course in microbiology.

These tutorials are designed to guide students' understanding of various fundamental concepts through animations, interactive exercises, and self-assessment. Each concept that is the subject of an Online Media Tutorial is identified by an icon similar to the one in the margin next to this paragraph, placed alongside the relevant figure in the text. Also on the website are additional materials for each chapter along with the popular ***Virtual Exam***, first introduced with *BBOM 9/e*. The Virtual Exam is a large pool of questions (written in an objective format, multiple choice, true-false, matching, and the like) keyed to individual chapters that students can use as a resource to help prepare for their real exams in the classroom. Virtual Exam questions have been assembled from actual examinations given in introductory microbiology courses in the United States that assign *BBOM* as a textbook. With the Virtual Exam, students can take an exam online and receive instant feedback on their readiness for exam day.

MEDIA TUTORIAL DNA Structure

A variety of supplements are available for instructors. First, a set of over ***350 Full Color Transparencies***, far more than is available with any other textbook of microbiology, accompany every adoption of *BBOM 10/e*. Although computer lectures are becoming the norm in many classrooms, the transparency is still the visual aid workhorse for many instructors. To help instructors in this regard, all of the most teachable figures in the book are covered in the transparency set. Second, a first-rate ***Instructor's Resource*** *CD-ROM* is available that contains virtually all of the art and photos from *BBOM 10/e* in Microsoft PowerPoint® to assist instructors in tailoring computer presentations to the goals and objectives of their particular course. In addition, all of the animations and exercises that appear on the student website will be on the Instructor's Resource CD-ROM. Whether one uses transparencies or CD-ROMs, the *BBOM 10/e* instructor package offers all of the necessary tools for developing clear, compelling, and stimulating presentations for the classroom.

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Although the authors have put a strong effort into assembling this classic tenth edition of *BBOM*, the book would never have come together in the way it did without the help of many other individuals. These include all the people at Prentice Hall/Pearson, including in particular our editor, Gary Carlson and his editorial assistant, Susan Zeigler, and our production editor, Debra Wechsler. Gary offered key editorial input into this project, including the commissioning of several very useful reviews. Susan kept the project moving along in the critical reviewing stages, and was extremely helpful in dealing with author requests. Debra, in her usual thorough and professional way, is largely responsible for the beautiful appearance of the final product. Through everyone's gallant efforts in the publishing side of this book, the authors had more freedom than usual to contemplate issues such as organization, content, and pedagogy.

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Any errors in this book, either those of commission or omission, are, of course, solely the responsibility of the authors. In this regard, we list author contact information and would greatly appreciate receiving comments, suggestions, and corrections from users. The entire author team has been with the book through a number of editions now and have through the years developed rather "thick skins" to criticism. Thus, we would sincerely enjoy receiving the frank input of users concerning how the book could be made even better in the future.

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The field of microbiology grew out of the pioneering studies of a handful of early scientists, including the great Russian microbiologist, Sergei Winogradsky. While other giants of the early era focused on the importance of microorganisms as agents of disease, Winogradsky studied bacteria that link key nutrient cycles in nature. His remarkably accurate artistic depictions of microorganisms, such as the phototrophic purple sulfur bacteria shown here, helped other scientists of the day begin to grasp the vast metabolic diversity of microorganisms that we now know exists on Earth.

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