

Microbiology

微生物学

fourth edition

PRESCOTT · HARLEY · KLEIN



世界图书出版公司

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世界图书出版公司

西安·北京·广州·上海

(陕)新登字 014 号

陕版出图字 著作权合同登记 25—1999—031 号

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ISBN 0—697—35439—3

This edition is permitted by arrangement with McGraw—Hill Book Co. Singapore

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by Prescott et al.

任卫军 重印责任编辑

世界图书出版公司 重印发行

(西安市南大街 17 号 邮编:710001)

西安七二二六印刷厂印刷

787×1092 毫米 开本 1/16 印张:68.25 字数: 2184 千字

1999 年 7 月第 1 次印刷

ISBN 7-5062-2252-X/R • 390
Wx2252 定价:(精)410.00 元

PREFACE

Books are the carriers of civilization. Without books, history is silent, literature dumb, science crippled, thought and speculation at a standstill. They are engines of change, windows on the world, lighthouses erected in a sea of time.

—Barbara Tuchman

Microbiology is an exceptionally broad discipline encompassing specialties as diverse as biochemistry, cell biology, genetics, taxonomy, pathogenic bacteriology, food and industrial microbiology, and ecology. A microbiologist must be acquainted with many biological disciplines and with all major groups of microorganisms: viruses, bacteria, fungi, algae, and protozoa. The key is balance. Students new to the subject need an introduction to the whole before concentrating on those parts of greatest concern to them. This text provides a balanced introduction to all major areas of microbiology for a variety of students. Because of this balance, the book is suitable for courses with orientations ranging from basic microbiology to medical and applied microbiology. Students preparing for careers in medicine, dentistry, nursing, and allied health professions will find the text just as useful as those aiming for careers in research, teaching, and industry. Two quarters/semesters each of biology and chemistry are assumed, and an overview of relevant chemistry is also provided in appendix I.

Organization and Approach

The book is organized flexibly so that chapters and topics may be arranged in almost any order. Each chapter has been made as self-contained as possible to promote this flexibility. Some core topics are essential to microbiology and have been given more extensive treatment. The chapters that cover these topics (chapters 2–18 and 29–32) are somewhat longer than others and may be combined with a selection of noncore chapters to achieve the desired orientation, whether basic, applied, or medical. The first six parts of the text (chapters 1–27), which cover the more general aspects of microbiology, also are available as a separate paperback volume.

The book is divided into 11 parts. The first 5 introduce the foundations of microbiology: the development of microbiology, the structure of microorganisms, microbial growth and

its control, metabolism, microbial genetics, and the nature of viruses. Part Six is a survey of the microbial world. In the fourth edition, the bacterial survey closely follows the general organization of forthcoming second edition of *Bergey's Manual of Systematic Bacteriology*. Because the classification of the second edition is so different from that of the current edition of *Bergey's Manual*, we have tried to make the transition to the new classification as easy as possible for the student. Although principal attention is devoted to bacteria, eucaryotic microorganisms receive more than usual coverage. Fungi, algae, and protozoa are important in their own right. The introduction to their biology in chapters 25–27 is essential to understanding topics as diverse as clinical microbiology and microbial ecology. Part Seven discusses symbiotic associations and parasitism in depth, providing a good foundation for the later survey of specific diseases. Three chapters in Part Eight describe in detail all major aspects of the immune response. Part Nine begins with an introduction to antimicrobial chemotherapy, epidemiology, and clinical microbiology. This is followed by a survey of the major human microbial diseases. The disease survey is primarily organized taxonomically on the chapter level; within each chapter diseases are covered according to mode of transmission. This approach provides flexibility and allows the student easy access to information about any disease of interest. The survey is not a simple cataloguing of diseases; diseases are included because of their medical importance and their ability to illuminate the basic principles of disease and resistance. Part Ten focuses on the relationship of microorganisms to aquatic and terrestrial environments. Chapter 40 presents the general principles underlying microbial ecology and environmental microbiology so that the chapters on aquatic and terrestrial habitats can be used without excessive redundancy. Part Eleven concludes the text with an introduction to food and industrial microbiology. Five appendices aid the student with a review of some basic chemical concepts and with extra information about important topics not completely covered in the text.

Many substantial changes and improvements have been made in the fourth edition, including the following:

1. The chapter on taxonomy, chapter 19, has been completely rewritten to place a greater emphasis on phylogenetic approaches and rRNA comparisons. It also contains an introduction to the upcoming second edition of *Bergey's Manual*.
2. The bacterial survey chapters (chapters 20–24) have been reorganized to follow the classification system of the second edition of *Bergey's Manual*. Wherever possible, the second edition is compared with the first edition. In order to make the transition easier for the student, appendix IV contains an outline of relevant portions of the first edition classification and page numbers for coverage of many of the most important bacteria. In this way the book can be used in the context of the first edition of *Bergey's Manual* even though it follows the classification of the second edition.
3. New references have been added through early 1998 and some older references deleted.
4. New topics and sections have been added and others have been substantially revised. Some examples are the following:
 - a. Chapter 9—The material on ATP synthase structure and function has been updated.
 - b. Chapter 11—There is new material on (1) domains and protein folding and (2) protein splicing, inteins, and exteins.
 - c. Chapter 13—A discussion of directed- or adaptive-mutation has been added.
 - d. Chapter 14—There is a new section on the process of whole genome sequencing and what has been learned thus far from genome sequences. A new box describes the procedure for DNA sequencing.
 - e. Chapter 15—A section on the use of artificial chromosomes in genetic engineering has been added.
 - f. Chapter 18—There is new material on virus life cycles, particularly the reproduction of hepadnaviruses.
 - g. Chapters 20–24—Every chapter in the procaryotic survey has new tables summarizing the characteristics of important genera. Descriptions of many genera have been added or expanded, for example: *Picrophilus*, *Methanopyrus*, *Aquifex*, *Thermotoga*, *Planctomyces*, *Burkholderia*, *Helicobacter*, *Propionibacterium*, *Bifidobacterium*, and *Hellobacterium*.
 - h. Chapters 25–27—In the last few years, phylogenies of true fungi (Eumycota), slime molds, water molds, algae, and protozoa have been developed using rRNA data and the results of ultrastructural studies. These are described at several points during the eucaryotic survey.
 - i. Chapter 28—A discussion of syntrophism has been added with the anaerobic, methanogenic microbial system as an example.
 - j. Chapter 29—New discussions of pathogenicity islands and the type III secretion system have been added.
 - k. Material on cytokines and their receptors has been updated throughout the immunology chapters.
 - l. Chapters 36–39—Discussions of many newly emerging viral, bacterial, fungal, and protozoan diseases are included in the disease survey.
 - m. Chapter 40—The chapter contains several changes and improvements: a discussion of the relationship between microbial ecology and environmental microbiology, a description of new molecular techniques used in environmental studies, current information on the recently discovered chemical-based microbial ecosystems, and updated material on nutrient cycling.
 - n. Chapter 41—New topics include an introduction to zoospore aquatic fungi, a description of the toxic dinoflagellate *Pfiesteria piscicida*, and a discussion of the impact of dams on aquatic ecology. The discussions of sewage treatment and the survival of *E. coli* O157:H7 in the aquatic environment have been updated.
 - o. Chapter 42—The discussions of nitrogen fixation and mycorrhizal relationships have been updated and improved.
 - p. Chapter 43—The discussions of molecular techniques for food analysis and rapid identification procedures for pathogens have been updated. New material on *E. coli* O157:H7 transmission and control has been added.
 - q. Chapter 44—Discussions of evolutionary biotechnology and natural attenuation have been added. The latest information on bioremediation and reductive dehalogenation is included.

This text is designed to be an effective teaching tool. A text is only as easy for a student to use as it is easy to read. Readability has been enhanced by using a relatively simple, direct writing style, many section headings, and an organized outline format within each chapter. The level of difficulty has been carefully set with the target audience in mind. During preparation of the fourth edition, every sentence was carefully checked for clarity and revised when necessary. The American Society for Microbiology's *ASM Style Manual* conventions for nomenclature and abbreviations have been followed as consistently as possible.

The many new terms encountered in studying microbiology are a major stumbling block for students. This text lessens the problem by addressing and reinforcing a student's vocabulary development in three ways: (1) no new term is used without being clearly defined (often derivations also are given)—a student does not have to be familiar with the terminology of microbiology to use this text; (2) the most important terms are printed in boldface when first used; and (3) a very extensive, up-to-date, page-referenced glossary is included at the end of the text.

Because illustrations are critical to a student's learning and enjoyment of microbiology, all illustrations are full-color, and as many color photographs as possible have been used. Color not only enhances the text's attractiveness but also increases each figure's teaching effectiveness. Considerable effort has gone into making the art as attractive and useful as possible. Where necessary, the art in the third edition has been revised and improved for use in the fourth edition. All new line art has been produced under the direct supervision of the authors and designed to illustrate and reinforce specific points in the text. Consequently every illustration is directly related to the narrative and specifically cited where

appropriate. Great care has been taken to position illustrations as close as possible to the places where they are cited. Illustrations and captions have been reviewed for accuracy and clarity.

Themes in the Book

At least seven themes permeate the text, though a particular one may be more obvious at some points than are others. These themes or emphases are the following:

1. The development of microbiology as a science
2. The nature and importance of the techniques used to isolate, culture, observe, and identify microorganisms
3. The control of microorganisms and reduction of their detrimental effects
4. The importance of molecular biology for microbiology
5. The medical significance of microbiology
6. The ways in which microorganisms interact with their environments and the practical consequences of these interactions
7. The influences that microorganisms and microbiological applications have on everyday life

These themes help unify the text and enhance continuity. The student should get a feeling for what microbiologists do and for how their activities affect society.

Aids to the Student

It is hard to overemphasize the importance of pedagogical aids for the student. Accuracy is most important, but if a text is not clear, readable, and attractive, up-to-dateness and accuracy are wasted because students will not read it. Students must be able to understand the material being presented, effectively use the text as a learning tool, and enjoy reading the book.

To be an effective teaching tool, a text must present the science of microbiology in a way that can be clearly taught and easily learned. Therefore many aids are included to make the task of learning more efficient and enjoyable. Following the preface a special section addressed to the student user reviews the principles of effective learning, including the SQ4R (survey, question, read, revise, record, and review) study technique. Each chapter contains the following:

1. *Opening quote(s)*: These are designed to perk student interest and provide perspective on the chapter's contents.
2. *Chapter outline*: The chapter outline, with page numbers, includes all major headings in the chapter. This helps the reader locate particular topics of interest.
3. *Chapter concepts*: Several statements briefly summarize some of the most important concepts the student should master.
4. *Chapter preface*: One or two short paragraphs preview the chapter's contents and relate it to the rest of the text. The preface is not a summary but allows the student to put the chapter in perspective at the start.
5. *Boldfaced terms*: Important terms are emphasized and clearly defined when they are first used.

6. *Chapter summaries*: A series of brief, numbered statements is designed to serve more as a study guide than as a complete, detailed summary of the chapter.
7. *Key terms*: A list of all boldfaced terms is provided at the end of the chapter to emphasize the most significant facts and concepts. Each term is page-referenced to the page on which the term is first introduced in the chapter.
8. *Review questions and activities*: Two kinds of review questions appear in each chapter. A small box with one to five brief review questions is located at the end of most major sections. These questions help the student master the section's factual material and major concepts before continuing with the chapter. An example of these in-chapter review questions from page 50 has been reproduced here.

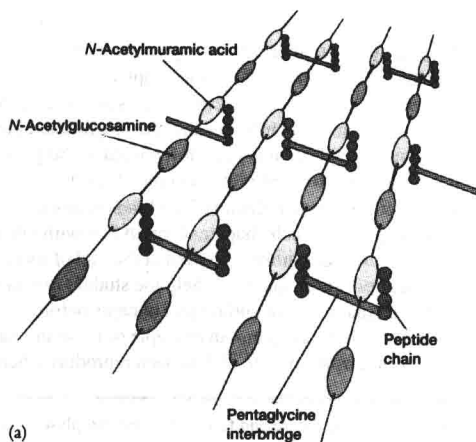
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1. Briefly describe the nature and function of the cytoplasmic matrix and the ribosome. What is a protoplast?
 2. What kinds of inclusion bodies do procaryotes have? What are their functions?
 3. What is a gas vacuole? Relate its structure to its function.
 4. What are molecular chaperones and heat-shock proteins? Describe their functions.
-


The "Questions for Thought and Review" section at the end of the chapter contains factual questions and some synthetic questions to aid the student in reviewing, integrating, and applying the material in the chapter.

9. *Multimedia-supported illustrations*: Throughout the text the reader will find illustrations of microbiological concepts and processes that can be supplemented with full-color video, animations, or interactive screens from the new second edition of *Microbes in Motion* (0-697-24596-9), the interactive CD-ROM available from WCB/McGraw-Hill. The reader will be able to easily recognize these figures, as the figure legends are preceded by a CD icon. Figure 3.23a, is one example of such an illustration (see next page).
10. *Correlation guide to Microbes in Motion*: To facilitate finding corresponding information on the multimedia-supported illustrations, a correlation guide is provided in the Instructor's Manual and Student Study Guide. The *Microbes in Motion* CD-ROM is organized into 17 topical "books," the books are divided up into "chapters," and the chapters have numbered "pages." For each multimedia-supported illustration, the correlation guide directs the reader to the book, chapter, and page on the CD-ROM where corresponding material can be found. The correlation guide entry is shown here for the multimedia-supported illustration referred to above.

Fig. 3.23 Bacterial Structure and Function Book
Cell Wall Chapter/Peptidoglycan Topic
pp. 2 & 3

11. *Additional readings*: References are provided for further study. Most are reviews, monographs, and *Scientific American* articles rather than original research papers. Publications cited in these reviews introduce sufficiently interested students to



 **Figure 3.23 Peptidoglycan Structure.** A peptidoglycan segment showing the polysaccharide chains, tetrapeptide side chains, and peptide interbridges. (a) A schematic diagram.

the research literature. References through early 1998 have been included. The reference sections also are organized into topical groups that correspond to the major sections in each chapter. This arrangement provides ease of access for students interested in particular topics.

12. *Cross-reference notes:* These notes refer the student to major topics that are difficult and may need review in order to understand the current material. They also point the student either forward or backward to a related item of unusual interest or importance. An example of the usage of the cross-reference note from page 129 has been reproduced here.

Electron transport and aerobic respiration (pp. 169–74).

Fermentation (pp. 174–76).

Anaerobic respiration (pp. 176–77).

13. **Boxed readings:** Most chapters also contain one or more boxes, which describe items of interest that are not essential to the primary thrust of the chapter. Topics include currently exciting research areas, the practical impact of microbial activities, items of medical significance, historical anecdotes, and descriptions of extraordinary microorganisms. An example of a boxed reading from page 302 has been reduced and reproduced here.

Besides the chapter aids the text also contains a glossary, an index, and five appendices. The extensive *glossary* defines the most important terms from each chapter and includes page references. Where desirable, phonetic pronunciations also are given. Most of the glossary definitions have not been taken directly from

the text but have been rewritten to give the student further understanding of the item. To improve ease of use, the fourth edition has a large, detailed *index*. It has been carefully designed to make text material more accessible. The *appendices* aid the student with extra review of chemical principles and metabolic pathways and provide further details about the taxonomy of bacteria and viruses.

Supplementary Materials

Many supplementary materials are available to help instructors with their presentations and general course management.

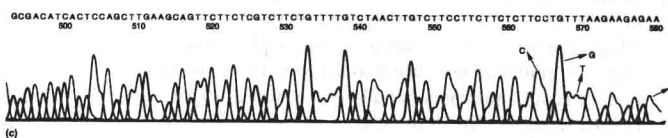
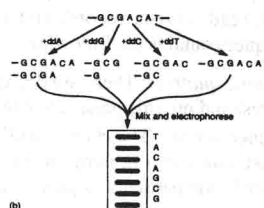
1. An *Instructor's Manual*, written by Ralph Rascati, Kennesaw College, includes a list of transparencies, a list of two slide sets, and a correlation guide that ties *Microbiology*, fourth edition, to the second edition of the *Microbes in Motion* CD-ROM. In addition, the number of test questions has been increased to about 60 for each chapter. This extensive battery of more than 2,600 test items is a powerful instructional tool.
2. The *WCB/McGraw-Hill Microtest* is a computerized testing and classroom management service that is offered free on request to adopters of this text. The service provides a database of objective questions for preparing exams and a grade-recording program. The software requires no programming experience and is available in Windows, and Mac formats.
3. A set of 150 full-color acetate *transparencies* is available and may be used to supplement classroom lectures.
4. The *WCB/McGraw-Hill Visual Resource Library* contains 300 carefully selected illustrations from *Microbiology*, fourth

Box 14.2

DNA Sequencing

The most widely used sequencing technique is that developed by Frederick Sanger in 1973. This approach uses dideoxynucleotide triphosphates (ddNTPs) in DNA synthesis. These molecules resemble normal nucleotides except that they lack a 3'-hydroxyl group. They can add to the growing end of the chain, but terminate the synthesis catalyzed by DNA polymerase because more nucleotides cannot be added. To perform the sequencing, the DNA to be sequenced is mixed with a primer. DNA polymerase I, normal nucleoside triphosphates, and a small amount of one of the dideoxynucleotides that has been labeled with a fluorescent dye (each ddNTP is labeled with a dye of a different color). DNA synthesis begins with the primer. The reaction is then stopped by the addition of EDTA and NTP (see Box figure *b*). The result is a series of fragments of varying lengths. Four reactions are run, each with a different fluorescent ddNTP. The mix with dATTP produces fragments with an A terminus; the mix with dGTP produces fragments with G terminals; and so forth. The fluorescent fragments are separated by size using thin layer chromatography on polyacrylamide gels to separate them from one another based on size. A DNA sequence can be read directly from the gels beginning with the smallest or fastest moving band and moving to the largest or slowest moving band. The bands are read from a single gel. If the sequence is to be read visually, four lanes are used. Each lane contains each reaction mix (see Box figure *a*). In automated systems the products from the four reactions are mixed and electrophoresed together. Because each ddNTP fluoresces with a different color, a detector can scan the gel and read the sequence from the order of colors in the bands (see Box figure *b*, *c*).

The Sanger Method for DNA Sequencing. (a) A sequencing gel with four separate lanes. The sequence begins, reading from the bottom, CAAAAACGGACCGGGTGTAC. (b) An example of sequencing by use of fluorescent dideoxynucleoside triphosphates. See text for details. (c) Part of an automated DNA sequencing run. Bases 493 to 499 were used as the example in (b).



edition, on CD-ROM with easy to use presentation software. The *Interactive Slide Show* program allows you to present the ready to play slide show offered on CD-ROM, and the *Slide Editor* program enables you to maneuver among the images to create your own multimedia presentation.

5. A set of *projection slides* provides clinical examples of diseases to supplement the illustrations in the text. A second set of *projection slides* provides examples of microbial specimens.
6. A *Student Study Guide* by Ralph Rascati contains chapter objectives, focus questions, mastery tests, and other activities to aid student comprehension.
7. The second edition of *Microbes in Motion* is an interactive CD-ROM, now for both Windows and Mac, that brings microbiology to life. This easy to use tutorial can go from the classroom to the resource center to your students' own personal computers. *Microbes in Motion* brings discovery back into the learning and education process through interactive screens, animations, video, audio, and hyperlinking questions. The applications of this CD-ROM are only as limited as your good ideas.

Two other CD-ROMs are also available from WCB/McGraw-Hill: *Hyper Clinic* (Windows), by Lewis Tomalty and Gloria Delisle, which provides a complete survey of clinical microbiology—including numerous case studies; and *Identibacter interactus*, an information-rich simulation of the bacterial-unknown laboratory exercise.

8. A fourth edition of the *laboratory manual*, *Laboratory Exercises in Microbiology*, by John P. Harley and Lansing M. Prescott, has been prepared to accompany the text. This manual is directly correlated with the text and designed to be used with it (although it may be used easily with other microbiology textbooks). Like the text the laboratory manual provides a balanced introduction to laboratory techniques and principles that are important in each area of microbiology. The class-tested exercises are modular and short so that an instructor can easily choose only those exercises that fit his or her course. The fourth edition of the manual contains recipes for all reagents and media. Each exercise in this manual can also be customized by combining the exercises with one's own materials. The local WCB/McGraw-Hill representative should be contacted for more details on this custom publishing service. A *lab resource guide* has complete answers to all laboratory report questions.
9. A set of 305, 3" × 5" *Microbiology Study Cards* prepared by Kent M. Van De Graaff, F. Brent Johnson, Brigham Young University, and Christopher H. Creek features complete descriptions of terms, clearly labeled drawings, clinical information on diseases, and much more.

Acknowledgments

The authors wish to thank the reviewers, who provided detailed criticism and analysis. Their suggestions greatly improved the final product.

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Publication of a textbook requires the effort of many people besides the authors. We wish to express special appreciation to the editorial and production staffs of WCB/McGraw-Hill for their excellent work. In particular, we would like to thank Elizabeth Sievers, our senior developmental editor, for her patience, guidance, and support. Terry Stanton, our developmental editor, worked extremely hard to get the manuscript ready for production. The project manager, Vicki Krug, supervised production with commendable attention to detail. Brenda Ernzen capably coordinated new and revised artwork. Beatrice Sussman, our copy editor for both the second and third editions, once again contributed greatly to the text's clarity, consistency, and readability.

The authors wish to especially thank John G. Holt, the former editor-in-chief of *Bergey's Manual*, and George M. Garrity, the current editor-in-chief of *Bergey's Manual*, for their aid in the preparation of the fourth edition. Both contributed time and expertise most generously. Our revision of the material on bacterial classification would not have been possible without their assistance.

Finally, but most important, we wish to extend appreciation to our families for their patience and encouragement, especially to our wives, Linda Prescott, Jane Harley, and Sandra Klein. To them, we dedicate this book.

Lansing M. Prescott
 John P. Harley
 Donald A. Klein

TO THE STUDENT

One of the most important factors contributing to success in college, and in microbiology courses, is the use of good study techniques. This textbook is organized to help you to study more efficiently. But even a text with many learning aids is not effective unless used properly. Thus this section briefly outlines some practical study skills that will help ensure success in microbiology and make your use of this textbook more productive. Many of you already have the study skills mentioned here and will not need to spend time reviewing familiar material. These suggestions are made in the hope that they may be useful to those who are unaware of approaches like the SQ4R technique for studying textbooks.

Time Management and Study Environment

Many students find it difficult to study effectively because of a lack of time management and a proper place to study. Often a student will do poorly in courses because not enough time has been spent studying outside class. For best results you should plan to spend at least an average of four to eight hours a week outside class working on each course. There is sufficient time in the week for this, but it does require time management. If you spend a few minutes early in the morning planning how the day is to be used and allow adequate time for studying, much more will be accomplished. Students who make efficient use of every moment find that they have plenty of time for recreation.

A second important factor is a proper place to study so that you can concentrate and efficiently use your study time. Try to find a quiet location with a desk and adequate lighting. If possible, always study in the same place and use it only for studying. In this way you will be mentally prepared to study when you are at your desk. This location may be in the dorm, the library, a special study room, or somewhere else. Wherever it is, your study area should be free from distractions—including friends who drop by to socialize. Much more will be accomplished if you really study during your designated study times.

Making the Most of Lectures

Attendance at lectures is essential for success. Students who chronically miss classes usually do not do well. To gain the most from lectures, it is best to read any relevant text material beforehand. Be prepared to concentrate during lectures; do not simply sit back passively and listen to the instructor. During the lecture record your notes in a legible way so that you can understand them later. It is most efficient to employ an outline or simple paragraph format. The use of abbreviations or some type of shorthand notation often is effective. During lecture concentrate on what is being said and be

sure to capture all of the main ideas, concepts, and definitions of important terms. Do not take sketchy notes assuming that you will remember things because they are easy or obvious; you won't. Diagrams, lists, and terms written on the board are almost always important, as is anything the instructor clearly emphasizes by tone of voice. Feel free to ask questions during class when you don't understand something or wish the instructor to pursue a point further. Remember that if you don't understand, it is very likely that others in the class don't either but simply aren't willing to show their confusion. As soon as possible after a lecture, carefully review your notes to be certain that they are complete and understandable. Refer to the textbook when uncertain about something in your notes; it will be invaluable in clearing up questions and amplifying major points. When studying your notes for tests, it is a good idea to emphasize the most important points with a felt-tip marker just as you would when reading the textbook.

Studying the Textbook

Your textbook is one of the most important learning tools in any course and should be very carefully and conscientiously used. Many years ago Francis P. Robinson developed a very effective study technique called SQ3R (survey, question, read, recite, and review). More recently L. L. Thistlethwaite and N. K. Snouffer have slightly modified it to yield the SQ4R approach (survey, question, read, revise, record, and review). This latter approach is summarized below:

1. *Survey.* Briefly scan the chapter to become familiar with its general content. Quickly read the title, introduction, summary, and main headings. Record the major ideas and points that you think the chapter will make. If there are a list of chapter concepts and a chapter outline, pay close attention to these. This survey should give you a feel for the topic and how the chapter is approaching it.
2. *Question.* As you reach each main heading or subheading, try to compose an important question or two that you believe the section will answer. This preview question will help focus your reading of the section. It is also a good idea to keep asking yourself questions as you read. This habit facilitates active reading and learning.
3. *Read.* Carefully read the section. Read to understand concepts and major points, and try to find the answer to your preview question(s). You may want to highlight very important terms or explanations of concepts, but do not indiscriminantly highlight everything. Be sure to pay close attention to any terms printed in color or boldface since the author(s) considered these to be important.

4. *Revise.* After reading the section, revise your question(s) to more accurately reflect the section's contents. These questions should be concept type questions that force you to bring together a number of details. They can be written in the margins of your text.
5. *Record.* Underline the information in the text that answers your questions, if you have not already done so. You may wish to write down the answers in note form as well. This process will give you good material to use in preparing for exams.
6. *Review.* Review the information by trying to answer your questions without looking at the text. If the text has a list of key words and a set of study questions, be sure to use these in your review. You will retain much more if you review the material several times.

Preparing for Examinations

It is extremely important to prepare for examinations properly so that you will not be rushed and tired on examination day. All textbook reading and lecture note revision should be completed

well ahead of time so that the last few days can be spent in mastering the material, not in trying to understand the basic concepts. Cramming at the last moment for an exam is no substitute for daily preparation and review. By managing time carefully and keeping up with your studies, you will have plenty of time to review thoroughly and clear up any questions. This will allow you to get sufficient rest before the test and to feel confident in your preparation. Because both physical condition and general attitude are important factors in test performance, you will automatically do better. Proper reviewing techniques also aid retention of the material.

Further Reading

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- Shaw, H. 1976. *30 Ways to improve your grades*. New York: McGraw-Hill.
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