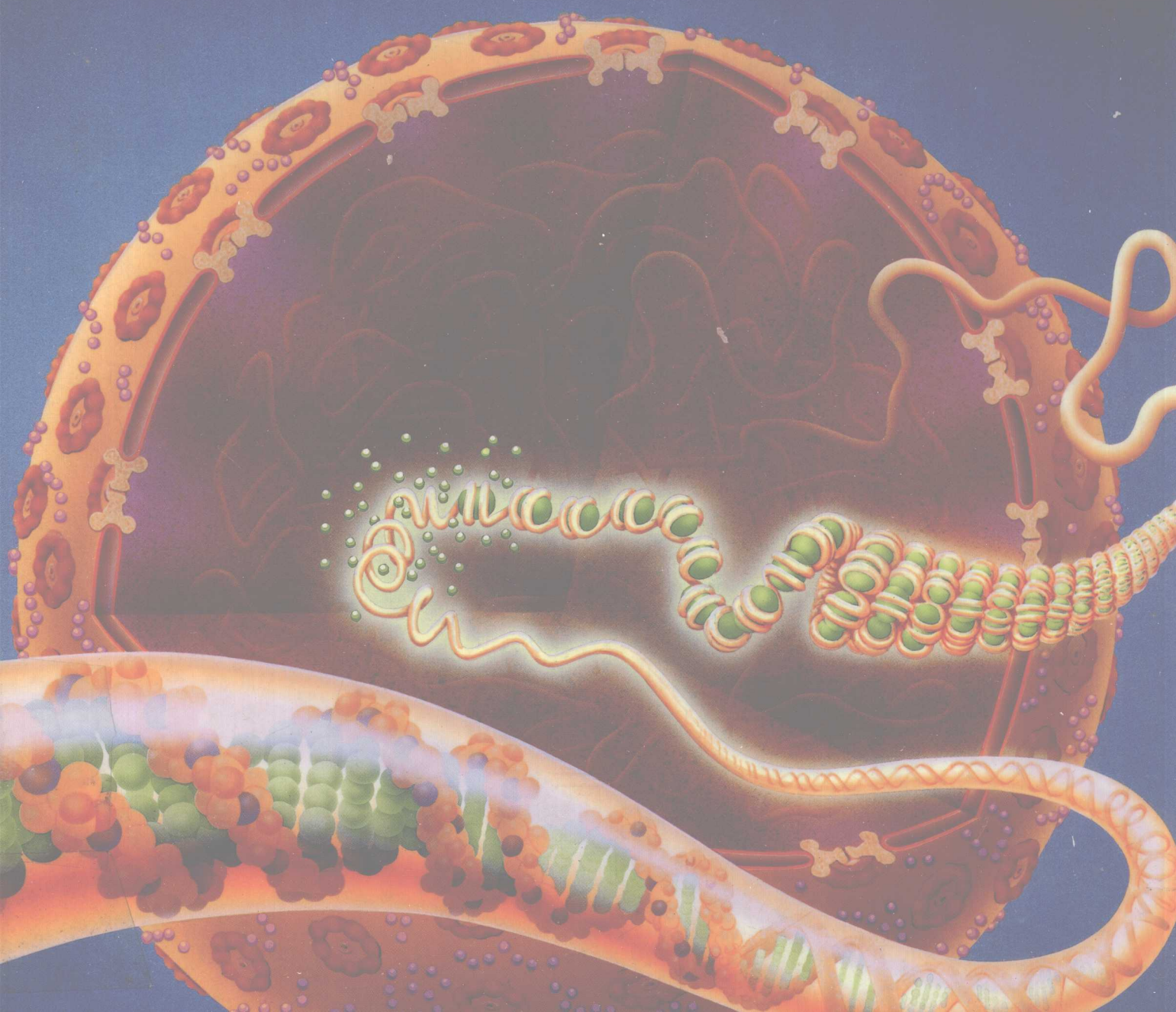
MOLECULAR AND CELLULAR BIOLOGY

Stephen L. Wolfe



MOLECULAR AND CELLULAR BIOLOGY

STEPHEN L. WOLFE
University of California at Davis

Wadsworth Publishing Company
Belmont, California
A Division of Wadsworth, Inc.

To my son, Christopher

BIOLOGY PUBLISHER: Jack C. Carey

EDITORIAL ASSISTANTS: Kathryn Shea, Laura Jersild

DEVELOPMENTAL EDITOR: Mary Arbogast

PRODUCTION AND ART SUPERVISION: Hal Lockwood, Christi Payne Fryday/Bookman Productions

PRODUCTION COORDINATOR: Harold Humphrey

PRINT BUYER: Karen Hunt

PERMISSIONS EDITOR: Robert Kauser

COPY EDITOR: Elizabeth F. Gehman

PAGE MAKE-UP: Judith Levinson

TECHNICAL ILLUSTRATORS: Darwen and Vally Hennings, John and Judy Waller, Illustrious, Inc., Academy ArtWorks, Inc., Precision Graphics

CHAPTER-OPENING ILLUSTRATORS: Chapters 1, 4, 5, 7, 9, 10, 12, 13, 14, 18, 20, 21, 24, 25, and 27 designed and rendered by Darwen and Vally Hennings; Chapters 6, 8, 11, 19, 22, and 26 designed by Darwen Hennings and rendered by Teresa Snyder; Chapters 2, 3, 15, 16, 17, and 23 designed and rendered by John and Judy Waller

COMPOSITOR: Syntax International

COLOR SEPARATOR: H&S Graphics, Inc.

PRINTER: R. R. Donnelley and Sons Company/Willard

COVER DESIGN: Stephen Rapley

COVER ILLUSTRATION: Tomo Narashima, based on a design by Darwen and Vally Hennings

45678910 96 95 94

Library of Congress Cataloging-in-Publication Data

Wolfe, Stephen L.
Molecular and cellular biology / Stephen L. Wolfe.
p. cm.
Includes bibliographical references and index
ISBN 0–534–12408–9
1. Cytology. 2. Molecular biology. I. Title.
QH581.2.W646 1993
574.87--dc20 92–38636

BOOKS IN THE WADSWORTH BIOLOGY SERIES

Environmental Science, 3rd, Miller

Resource Conservation and Management, Miller

Biology: Concepts and Applications, Starr

Biology: The Unity and Diversity of Life, 6th, Starr and Taggart

Biology of the Cell, 2nd, Wolfe

Cell Ultrastructure, Wolfe

Dimensions of Cancer, Kupchella

Evolution: Process and Product, 3rd, Dodson and Dodson

Introduction to Cell Biology, Wolfe

Oceanography: An Introduction, 4th, Ingmanson and Wallace

Plant Physiology, 4th, Devlin and Witham

Exercises in Plant Physiology, Witham et al.

Plant Physiology, 4th, Salisbury and Ross

Plant Physiology Laboratory Manual, Ross

Plants: An Evolutionary Survey, 2nd, Scagel et al.

Psychobiology: The Neuron and Behavior, Hoyenga and Hoyenga

Sex, Evolution, and Behavior, 2nd, Daly and Wilson

PREFACE

The aim of this book is to integrate molecular biology, biochemistry, and cell biology into a unified course of study. Until now, molecular biology texts have concentrated on gene structure and activity to the near exclusion of more "traditional" biochemistry and cell biology. This reflects a past tendency to throw out the baby with the bath water—to regard many of the findings and conclusions developed by traditional biochemical and cell biological investigations as unreliable and uninteresting because the research was conducted before the molecular revolution. However, the emphasis in molecular biology has now shifted from a concentration on genes for their own sake to the application of molecular genetic studies to all areas of cell biology and biochemistry. As a result, more traditional research areas—ion transport and the control of cell division come to mind as two examples—have become the subjects of highly productive investigations in which the powerful methods of molecular biology are producing many new findings and pushing these areas to the forefront of research.

With these developments in mind, this book offers a balanced view of contemporary molecular biology, biochemistry, and cell biology not currently available in other texts. The central topics of molecular biology are included, among them DNA structure, messenger RNA gene structure and activity, and the molecular methods for studying these genes. However, the molecular biology of genes encoding the other major RNA types is also emphasized, along with their regulation and the biochemistry of their transcription. These topics are integrated with the cell biology of the nucleus, including the structure of nucleosomes, chromatin, the nucleolus, and the nuclear envelope; the changes occurring in nucleosomes and chromatin during the shift between inactivity and gene transcription; and the role of the nuclear envelope in transport between the nucleus and cytoplasm. The organization of genes into genomes and the techniques of genetic engineering are also included in this integration. Similarly, the coverage of cell division includes an integrated view of the molecular biology and biochemistry of cell cycle genes and their regulation, DNA replication and repair, and the changes in nucleosome and chromatin structure that accompany cell division. The molecules, forces, and structures separating the chromosomes during mitotic cell division are also considered, as well as the molecular biology, biochemistry, and cell biology of genetic recombination during meiosis, the formation of gametes, and their functions in fertilization.

Among the more traditional topics of cell biology and biochemistry that are integrated with molecular biology and emphasized in this text are protein synthesis and the modification and distribution of newly synthesized proteins by the endoplasmic reticulum and Golgi complex; membrane structure and transport, and the role of ion transport in the generation and conduction of nerve impulses; the activities of mitochondria and chloroplasts in cellular metabolism, and the mechanisms governing genetic inheritance in these organelles; the roles of microtubules and microfilaments in the generation of motility and, with intermediate filaments, in cytoskeletal support; and the structure and function of the cell surface and extracellular matrix, along with the cellular regulatory mechanisms linked to receptors at the cell surface.

These topics are distributed between the chapters of text, which cover subjects that are central to most or all courses, and chapter Supplements, which add important specialized or peripheral information. This distribution keeps the chapters as direct and to the point as possible. Also included in the chapters are Information Boxes, presenting short but essential items of background information. By selecting among the material presented in the chapters and Supplements, an instructor can tailor the text to suit the aims of the course and its students.

To make the book as clear and graphic as possible, every topic that merits explanation by pictures as well as words is illustrated by a diagram or micrograph. The many light and electron micrographs, in particular, emphasize that molecular and biochemical processes have a structural basis and help relate these processes to cell biology. In addition, each chapter opens with a major piece of art that focuses interest and illustrates a central topic explained in that chapter.

Where possible, molecular and cellular biology and biochemistry are brought home to students by integrating examples from human biology, especially medicine. These examples show that the topics described in the book, as well as having scientific and academic importance, touch directly on human affairs. The regulation of cell division, for example, is illus-

trated by a description of the cell cycle controls that go awry in the transformation of normal cells into cancer cells; the organization of DNA sequences in genomes is elaborated by a discussion of genetic engineering and the genetic rearrangements underlying the production of antibodies, the immune response, and the rejection of transplanted tissues.

The findings, conclusions, and principles described in the text are presented in terms of experimental evidence drawn from work with prokaryotes, fungi, animals, and plants. Controversies as well as conclusions are presented in order to show that the body of scientific information in molecular and cellular biology is not fixed, and that many significant questions remain to be answered. This experimental foundation is bolstered by essays contributed by original investigators, presenting their experiences in the conception and execution of classic and contemporary experiments that have produced key contributions in molecular biology, biochemistry, and cell biology. The essays add a personal element to the information presented in the book and emphasize that this information is the result of experimental work by individual scientists. The essayists include both established researchers, who are essentially household names among biologists, and relative newcomers, who are likely to be among the next generation of famous names. Hopefully, in addition to piquing students' interest, the essays may help turn them toward the possibility of research as a career.

The spate of multiple-author textbooks in molecular and cellular biology has led to a belief that the information in this field has become so extensive that it lies beyond the reach of a single author. I hope this book will make it apparent that the opposite is true, and that coverage by a single author brings a degree of organization, integration, and unity that lies beyond even the most carefully prepared multiple-author text.

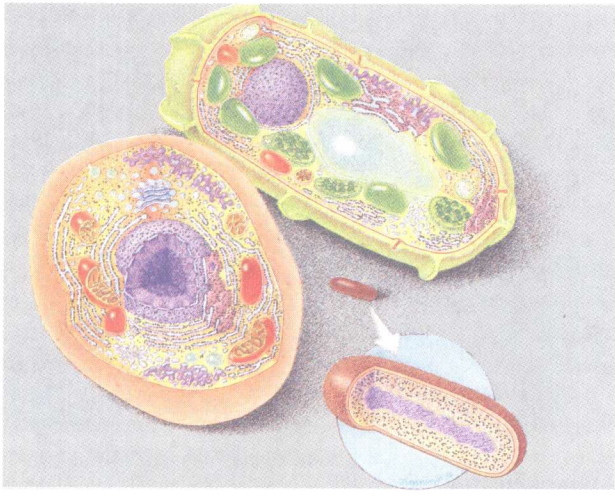
Although this is a single-author book, I must acknowledge my debt to the many people who have contributed to it. The book could not have been written without the help of colleagues and friends who reviewed the text and offered suggestions for improving its accuracy and content. I am also deeply indebted to the many investigators who generously supplied micrographs, diagrams, and tables. I must also acknowledge my debt to my biology editor, Jack Carey, who provided endless encouragement and guidance in the preparation of the text; to my developmental editor, Mary Arbogast, who provided expert editorial help and unscrambled more glitches than I care to remember; and to Hal Humphrey, Hal Lockwood, and Christi Fryday, who coordinated production at Wadsworth and Bookman Productions, and solved the innumerable problems attending publication of a book of this size and complexity. I am also indebted to Darwen and Vally Hennings, and John and Judy Waller, who prepared original art and redrew many of the diagrams sent by other authors. Darwen Hennings in particular was instrumental in the design and preparation of the more complex illustrations in the book, including the majority of drawings that serve as chapter openers.

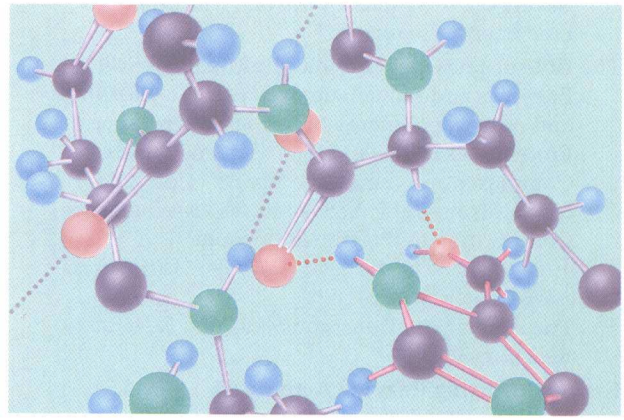
REVIEWERS

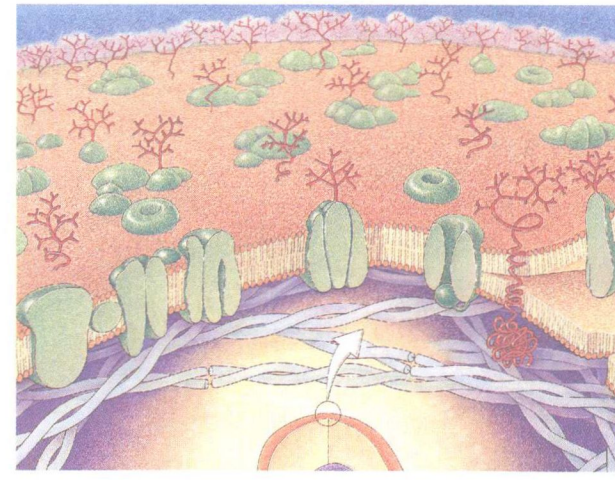
David Asai, *Purdue University*
Aimee Bakken, *University of Washington*
Stephen C. Benson, *California State University, Hayward*
Colin F. Blake, *Oxford University*
Douglas C. Braaten, *Washington University*
B. R. Brinkley, *University of Alabama*
Iain L. Cartwright, *University of Cincinnati*
G. P. Chapman, *University of London*
Susan Conrad, *Michigan State University*
David T. Denhardt, *University of Western Ontario*
William Dentler, *University of Kansas*
William Dunphy, *University of California, San Diego*
Douglas Easton, *State University College of Buffalo*
D. J. Finnegan, *University of Edinburgh*
Christine H. Foyer, *The University of Sheffield*
Carl Frankel, *Pennsylvania State University*
Michael Freeling, *University of California, Berkeley*
David Fromson, *California State University, Fullerton*
Leah T. Haimo, *University of California, Riverside*
Elizabeth D. Hay, *Harvard University*
John Hershey, *University of California, Davis*
Peter Heywood, *Brown University*
Ricky R. Hirschhorn, *University of Kentucky*
J. Kenneth Hoober, *Temple University*
Yasuo Hotta, *Nagoya University*
Lon Kaufman, *University of Illinois*
Charles C. Lambert, *California State University, Fullerton*
Elias Lazarides, *California Institute of Technology*
Mary Lee Ledbetter, *College of the Holy Cross*
John Lye, *University of Colorado*
Thomas Lynch, *University of Arkansas, Little Rock*
Robert MacDonald, *Northwestern University*
S. K. Malhotra, *University of Alberta*
Peter B. Moens, *York University*
Stephen M. Mount, *Columbia University*
Dominic Poccia, *Amherst College*
P. Elaine Roberts, *Colorado State University*
Thomas Roberts, *Florida State University*
Enrique Rodriguez-Boulan, *Cornell University*
John Ruffolo, *Indiana State University*
Robert Savage, *Swarthmore College*
David Saxon, *Morehead State University*
R. L. Seale, *Scripps Clinic Research Foundation*
Barbara Sears, *Michigan State University*
Joel Sheffield, *Temple University*
Sheldon S. Shen, *Iowa State University*
Roger Sloboda, *Dartmouth College*
Gary Stein, *University of Florida*
Herbert Stern, *University of California, San Diego*
Albert P. Torzilli, *George Mason University*
Fred Warner, *Syracuse University*
Ruth Welti, *Kansas State University*
Larry Williams, *Kansas State University*
John G. Wise, *University of California, Los Angeles*
William L. Wissinger, *St. Bonaventure University*
Debra J. Wolgemuth, *Columbia University*
D. L. Worcester, *University of Missouri*
Charles F. Yocum, *University of Michigan, Ann Arbor*

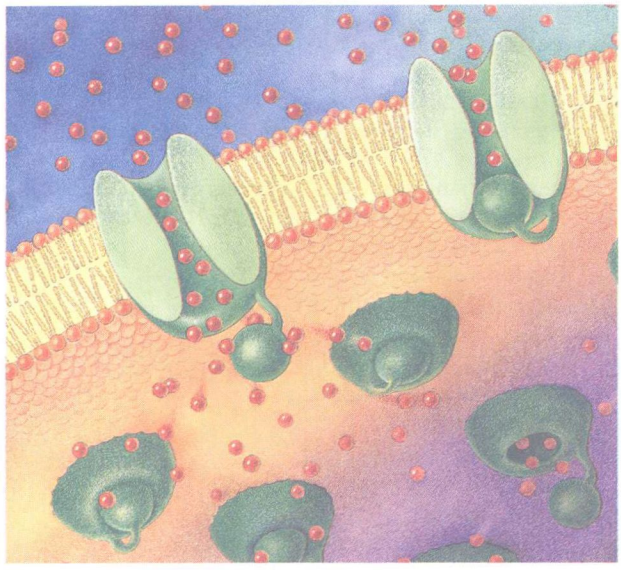
THE EXPERIMENTAL PROCESS ESSAYISTS

BRIEF CONTENTS









CHAPTER 6

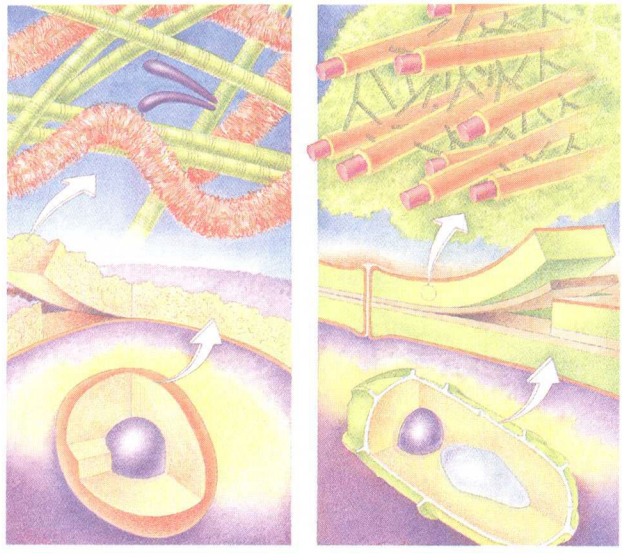
THE FUNCTIONS OF MEMBRANES IN IONIC AND MOLECULAR TRANSPORT

CHAPTER 7

THE CELL SURFACE AND INTERCELLULAR COMMUNICATION

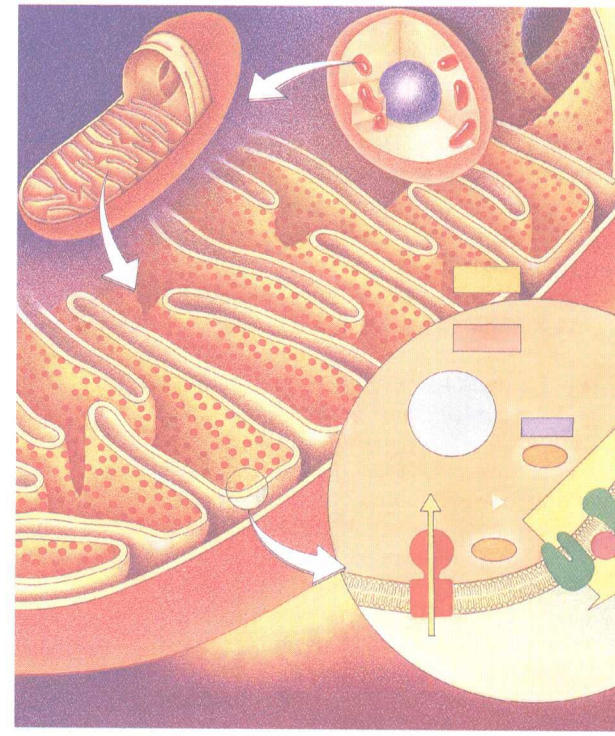
CHAPTER 8

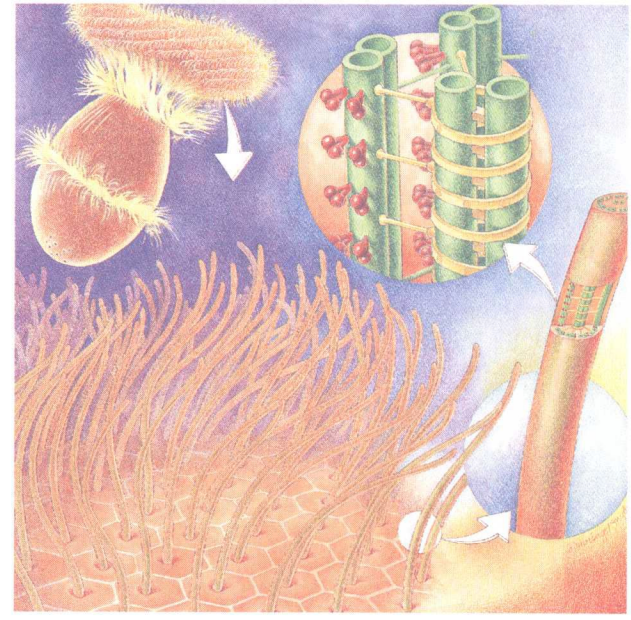
THE EXTRACELLULAR MATRIX OF EUKARYOTIC CELLS

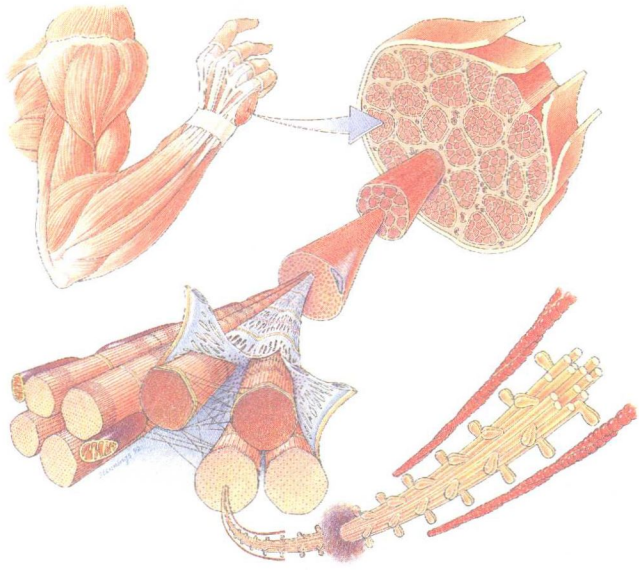


CHAPTER 9

ENERGY FOR CELL ACTIVITIES: CELLULAR OXIDATIONS AND THE MITOCHONDRION







CHAPTER 13

MICROTUBULES, MICROFILAMENTS, AND INTERMEDIATE FILAMENTS IN THE CYTOSKELETON

CHAPTER 14

THE NUCLEUS AND ITS MOLECULAR CONSTITUENTS