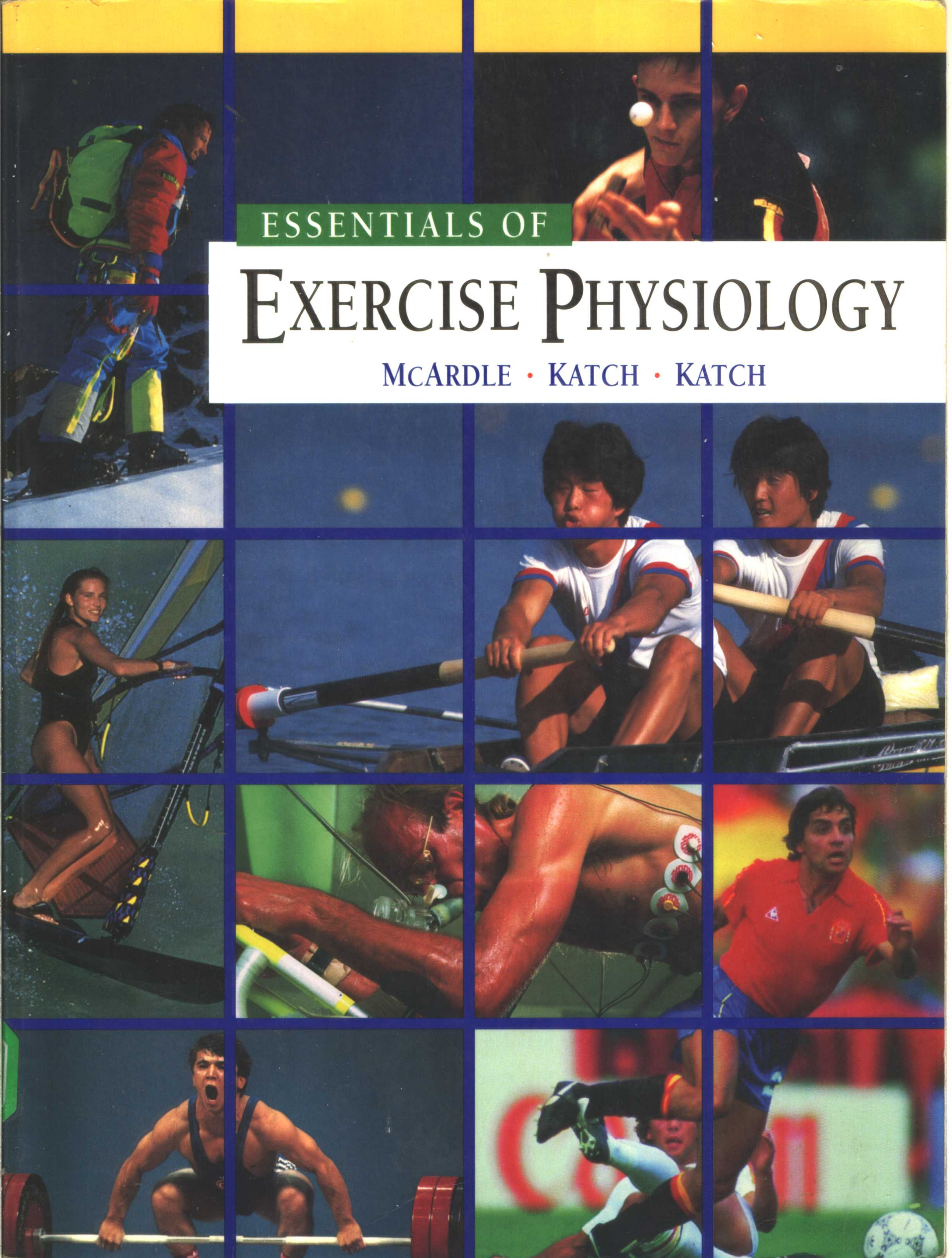

ESSENTIALS OF

EXERCISE PHYSIOLOGY

McARDLE · KATCH · KATCH

ESSENTIALS OF EXERCISE PHYSIOLOGY

WILLIAM D. MCARDLE
Queens College — CUNY
Professor, Department of Health and Physical Education
Flushing, New York

FRANK I. KATCH
Professor, Department of Exercise Science
University of Massachusetts
Amherst, Massachusetts

VICTOR L. KATCH
Professor, Department of Movement Science
Division of Kinesiology
Associate Professor, Department of Pediatrics
School of Medicine
University of Michigan
Ann Arbor, Michigan

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EXECUTIVE EDITOR: *J. Matthew Harris*
DEVELOPMENT EDITOR: *Lisa Stead*
PROJECT EDITOR: *R. Lukens*
PRODUCTION MANAGER: *Michael DeNardo*

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DEDICATION

This book is dedicated to three very special people who have contributed in important ways over the years to our writing projects. John "Jack" Spahr, Sr. was a senior partner of the company when the first edition of *Exercise Physiology* was published in 1982, and he was there when we needed him most during publication of the third edition in 1991. Jack, you were a pillar of strength and reason at just the right times. His son, John Spahr, Jr. was a welcome addition to our team when Jack retired. His strong leadership at Lea & Febiger enabled us to work diligently during the preparation of the third edition of *Exercise Physiology* and the fourth edition of *Introduction to Nutrition, Exercise, and Health.* John really cared, and personally took us under his wing to be sure everything went off without a hitch. If John or Jack had promised that something was going to be done (even if it was left out of the contract), there was no need to worry because their word was as good as gold. A handshake and a look in the eye were as binding as words in a contract. That's just the way they were — honest to the letter — and we know they had our best interests at heart. We are thankful you gave the final OK to add color graphics to our last three books, and for providing us with the latest in computer technology to improve efficiency.

Tom Colaiezzi was production manager for the entire time we've been associated with Lea & Febiger. Tom pulled every string possible to make things happen when others said it just couldn't be done. Tom, we know you did lots of little extra things without our having to ask. You've been a true friend, and we know you were behind us every step of the way. Your dedication to technical excellence has been chiefly responsible for the artistic success of the seven book projects we worked on together. You always will be very special to us.

Besides being really terrific people to work with, all three of you made believers out of us by demonstrating that interrelationships between business goals, educational goals, and personal relationships need not be at odds, but can successfully work in harmony towards a common end. We were proud to be part of the Lea & Febiger family tradition. Your patience, encouragement, honesty, integrity, and always a sense of fair play made our close working relationship with you something special. We already miss you guys in so many ways, and we'll think of you often.

We also dedicate this book to three fine and loving gentlemen. During the past year, Professor Franklin M. Henry, Dr. Albert Behnke, and Professor Thomas K. Cureton, Jr. passed way. Each of these men was a pioneer and giant in our field, and has left a legacy that will endure. We were privileged to have known these men well since our graduate years, and we will miss their close association, guidance, friendship, and constant support as mentors and colleagues. "Doc," we'll always cherish our long walks and talks, and try to remember that "words have meaning — choose them carefully." Al, we promise to "carry the torch on to the next generation," and Tom, even though we were not your students, you were our teacher and trusted friend. All three of you played important roles in our lives.

PREFACE

Need for the text. With the success of the first three editions of *Exercise Physiology: Energy, Nutrition, and Human Performance* also came constructive criticism. Many of our colleagues who taught a one semester course believed that the existing text simply contained too much material that could not be covered in a one semester course. In addition to the need for a somewhat more compressed text, many felt there was also a need for a text that was more practical and applied in its approach to exercise physiology. Some instructors told us they wanted a text that clearly outlined the learning objectives and expectations so that it would be clear to the student what he or she should be able to do with the information once it was learned. It also was felt that a text emphasizing only the essentials did not have to follow a research-oriented format to document the material. Rather, a listing of relevant references at the end of each chapter would suffice. Within the context of practicality, there was a need to refocus text material and apply it more to teaching and exercise training situations. The suggestion was made to intersperse brief summaries, interpretations, and applications of the latest research in the interrelated areas of exercise, sports nutrition, weight control, and health. In addition, there was strong sentiment, with which we readily agreed, that a new textbook should be generously illustrated with graphics and photos to emphasize the sports, training, and physical performance focus of the book's contents. When we considered all of the suggestions, we felt strongly that we could design a new textbook that would continue to achieve high educational standards, yet meet the specific needs of certain students and faculty. This was the genesis of *Essentials of Exercise Physiology.*

Organization. The *Essentials* text is designed for a two-column format. This enables us to present current and relevant text with graphics, including the supplementary material close to the chapter's main text. We have added an introductory chapter to make it easier for students with limited background in the sciences to integrate the basics of the biology and chemistry of cellular organization and structure, energy transfer and biologic work, acid-base balance, and cellular transport within the study of exercise physiology.

The textbook contains eighteen chapters with six major sections. Although the flow of the sections and the chapters within each section seemed to the authors to progress logically for an essentials-oriented, one semester exercise physiology course, this structure is by no means "cast in stone." Chapters, as well as parts within certain chapters, can stand alone. In this way, students with prerequisite biology or physiology coursework would not be obliged to read the material for which they have been previously adequately prepared. This pertains to the introductory chapter on biology and chemistry basics, as well as portions of those chapters that deal with the physiology of the pulmonary, cardiovascular, and neuromuscular systems.

Section I contains four chapters that deal with energy transfer and physical activity. The presentation moves from a discussion of the basics of energy transfer at rest to the dynamics of energy release during various levels of physical activity up to the maximum. Where possible, comparisons are made between trained and untrained and the influence of age, gender, and specific training on these responses. Discussion also covers various methods for assessing energy expenditure during exercise, as well as the requirements and capacities for energy metabolism in diverse forms of physical activity.

Section II focuses on food energy and the concept of optimal nutrition and its role in exercise physiology, human performance, and good health. Practical recommendations and guidelines are presented for the active man and woman. The area of sports nutrition is explored with emphasis on the importance of fluid balance and dietary carbohydrate to sustain heavy training in both short and long term exercise performance.

In *Section III*, four chapters explore the physiologic support systems for physical activity. Major emphasis is placed on the structure, function, and exercise and training responses of the pulmonary, cardiovascular, neuromuscular, and endocrine systems.

Section IV considers training for muscular strength and conditioning for anaerobic and aerobic power. Also presented are practical ways to evaluate the functional capacities of these systems.

Section V discusses the impact of environmental factors of heat, cold, and altitude, as well as ergogenic aids such as caffeine, bicarbonate drinks, anabolic steroids, red blood cell reinfusion, and oxygen inhalation on physiology and exercise performance.

Three chapters in *Section VI* explore the underlying rationale for evaluating body composition among groups of highly trained men and women. Also discussed are the interrelated factors often associated with obesity, and the efficacy of diet and exercise as a treatment for the overfat condition. The final chapter is about exercise, aging, and health, with emphasis on how regular exercise relates to the risks for coronary heart disease.

Pedagogical Features. Overall, each chapter has been streamlined without sacrificing the appropriate detail required for an essentials text. Where possible, we have expanded our presentation to include applications that relate to both males and females, as well as children and older adults. Specific unique features of the text include:

- *Learning Objectives.* Each chapter is prefaced by a list of important student learning objectives specifically related to the material contained in the chapter. This provides the student with specific guideposts as to the important information within the chapter.
- *Marginal Notes, Data, and Illustrations.* There are over 500 marginal notes appearing throughout the chapters. These augment the thrust of the text material with the most up-to-date information, definitions, examples, data, and research findings on particular topics covered in the chapter.
- *Close-Ups.* A "close-up" feature within each chapter focuses on a timely and important exercise, sport, or clinical topic in exercise physiology related to the chapter's contents.
- *Visual Augmentation.* Illustrations and action photographs are liberally used to amplify the material presented within a particular figure or text section. We have tried very hard to integrate the graphic and photographic material to enhance overall readability and clarity of the presentation.
- *Chapter Summaries.* There is a list of summary statements in each chapter. These statements pull together the important concepts and information in the chapter.
- *Meaningful References.* An accessible group of up-to-date, as well as "classic" references, many of which are review articles on a specific topic, appear at the end of each chapter. These references can serve as a starting point for exploring a particular topic area in greater depth.
- *Relevant Appendices.* Appendices are located at the end of the text. These include:
    1. The metric system and constants in exercise physiology
    2. Metabolic computations in open-circuit spirometry
    3. Energy costs tables for physical activities
    4. Age- and gender-specific equations to predict percent body fat.
    5. Frequently cited journals in exercise physiology

Graphics. The graphics in the textbook were rendered by Bobby Starnes of Electragraphics, Inc., Blountville, Tennessee, simply the best electronic artist we know. To those who have ever tried to master the intricacies of modern computerized drawing tools, or are thinking of trying, we hope you are as fortunate in your search for artistic help as we were when we hooked up with Bobby Starnes. His creative energies gave zing and pep (and lots of color) to our initial renderings and ideas. It takes a special person to work long hours into the night to make sure our deadlines were met. We hope that the quality of the artwork has enhanced the educational relevance of the textbook.

The authors would like to acknowledge our executive editor Matt Harris, project editor Ray Lukens, production manager Mike DiNardo, development editor Lisa Stead, and the dedicated staff at Lea & Febiger for believing in this project and seeing that it all came to fruition on time. We would also like to acknowledge the staff at ALLSPORT for their help in securing first rate photos for the chapter openers,

and to Mark Fox, (Box 113, Silverthorne, CO 80498) a superb phtographer whose many skills have enabled us to enhance our graphics with his excellent photographs.

STUDENT STUDY GUIDE AND WORKBOOK

The *Student Study Guide and Workbook* is a resource companion to the main textbook. Its purpose is to promote "active learning" by involving students in the learning process. There are four main sections to the study guide: Section I facilitates student understanding of text content by focusing on key terms and concepts (student-generated glossary), and on specific questions within each chapter. In order to answer the questions, students must read and understand the major points in the chapter. Also, a unique aspect of this section is the first crossword puzzles in exercise physiology. These puzzles facilitate learning in a fun and entertaining way. This section also includes 10 multiple choice and true/false questions to test the student's comprehension of the text. Section II includes the nutritive values of 2025 common foods, including fast-food items. It also includes a list showing the energy cost of over 240 physical activities. Section III contains practical assessment tests, including Health-Related Physical Fitness, Healthy Life-Style Assessment, Physical Readiness, Determining Desirable Body Weight, and different Flexiblity Tests. Section IV includes solutions to the crossword puzzles and answers to all chapter quizzes.

As an added feature, the *Food and Diet Analyzer™* computer program, an interactive graphics diet analysis program designed for professional and educational use, can be purchased separately or in combination with the *Student Study Guide and Workbook*. The computer program analyzes foods or combinations of foods that may be classified as recipes, meals, menus, or complete diets. The analyses include the weight and percentage of the RDA according to age and gender for 28 nutrients, including the proportions of protein, carbohydrate, fat, and alcohol. Diabetic exchanges, based on food group and nutrient content, and nutrient densities and ratios, can be determined automatically. The *Food and Diet Analyzer™* is an efficient, time-saving tool for analyzing and creating diets accurately. *Food and Diet Analyzer™* also can indicate nutritive deficiencies and excesses, and identify the sources of these deficiencies and excesses. Analyses can be listed on the screen or printed in graphic or tabular form, and can be used to complete several of the self-assessment tests in the appendix of the workbook. The *Student Study Guide and Workbook* and *Food and Diet Analyzer™* computer program can be ordered by filling out the single page, colored insert found with this book, or by mailing or faxing Fitness Technologies Press.

Fitness Technologies Press
1132 Lincoln Street
Ann Arbor, MI 48104
FAX (313)662-8153

Flushing, New York
Amherst, Massachusetts
Ann Arbor, Michigan

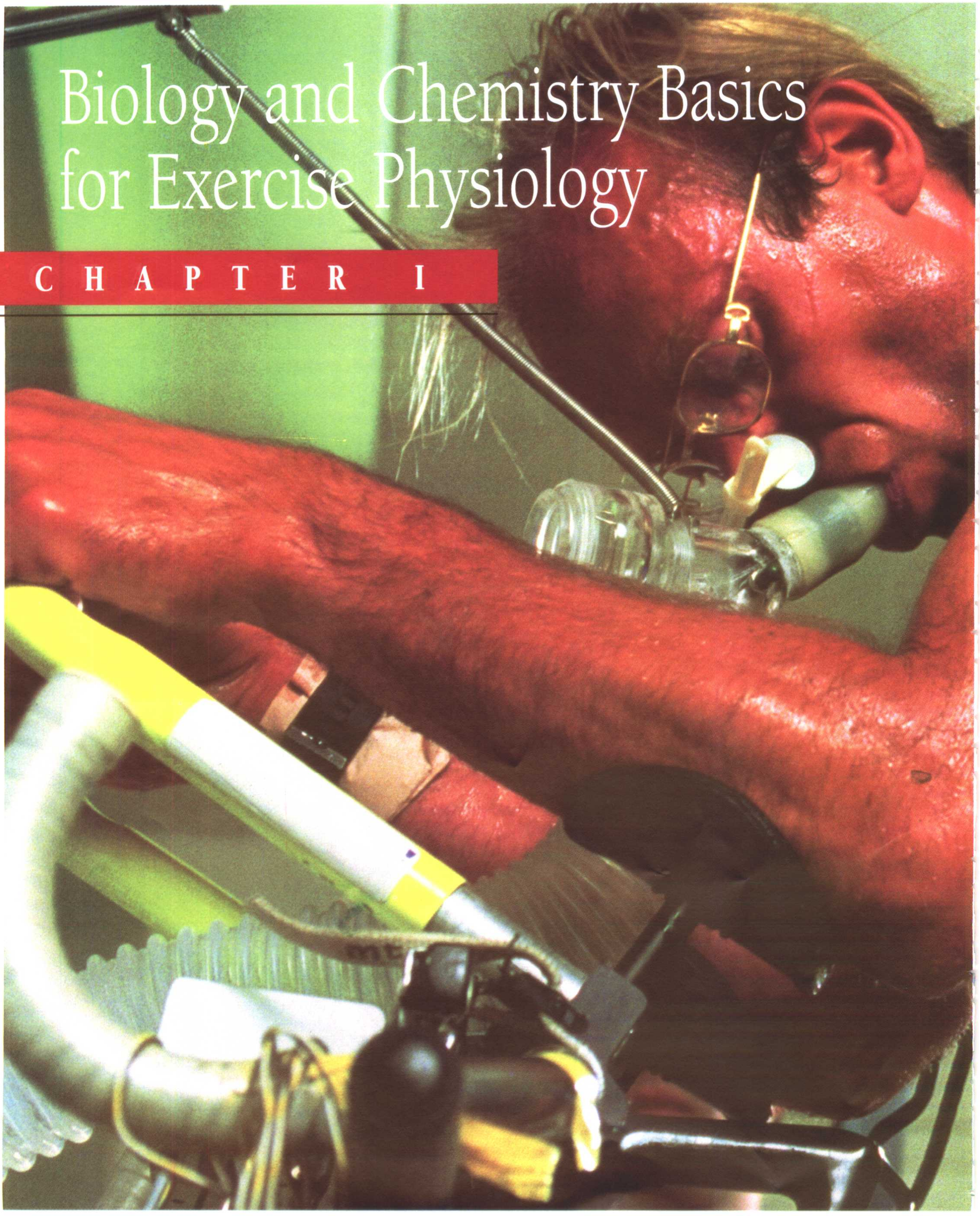
William D. McArdle
Frank I. Katch
Victor L. Katch

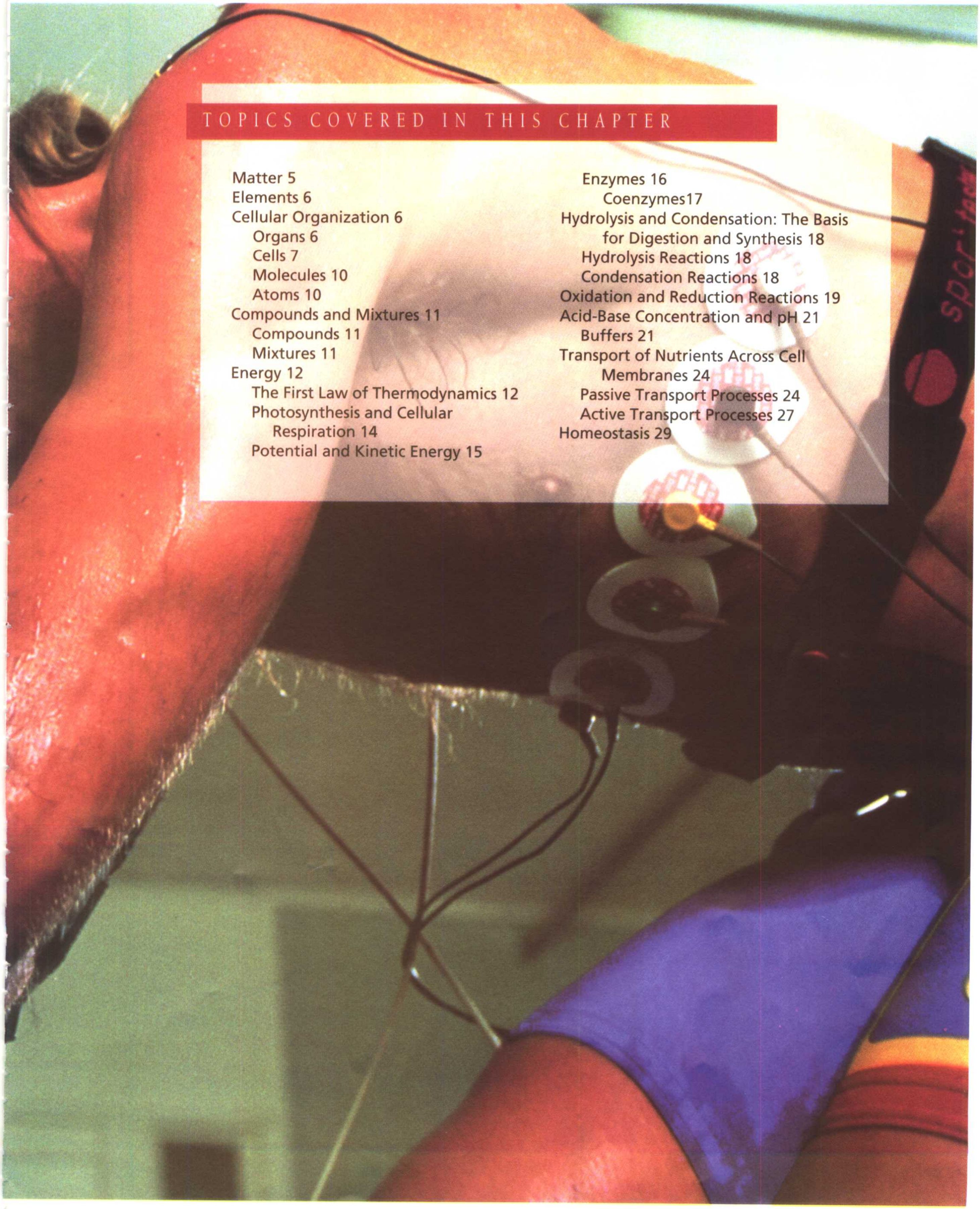
CONTENTS

ESSENTIALS OF EXERCISE PHYSIOLOGY

Biology and Chemistry Basics for Exercise Physiology

CHAPTER 1





TOPICS COVERED IN THIS CHAPTER

CHAPTER OBJECTIVES

After reading this chapter you should be able to:

- Define the terms mass, weight, and density.
- Outline the general biologic organization of the human body.
- Discuss the role of the plasma membrane, nucleus, and mitochondria in cellular function.
- Explain the concept of energy and its role in various forms of biologic work.
- Compare and contrast the processes of photosynthesis and respiration.
- Explain the role of enzymes and coenzymes in the body's chemical reactions.
- Discuss the processes of oxidation and reduction and provide examples related to exercise energy metabolism.
- Define the terms acid, base, and pH, and describe how the body regulates acid-base balance.
- Outline the different ways chemicals are exchanged between the cell and its surroundings.
- Define homeostasis and give examples of this regulatory process during exercise.

Biology and chemistry form the foundation for understanding almost every aspect of exercise physiology. Sometimes the picture is fairly clear as in the role of the pulmonary and cardiovascular systems in supplying oxygen to the active muscles. Often, however, interactions are more complex, as during the digestion and absorption of carbohydrates, lipids, and proteins, or in the processes of energy transfer from these nutrients during diverse forms of physical activity.

In this introductory chapter, we review some basic definitions and concepts in biology and chemistry as they relate to energy expenditure and human exercise performance. Knowledge of these fundamentals will help you to appreciate what goes on "behind the scenes" as the various nutrients undergo chemical transformations during tissue synthesis or their conversion to useful energy while at rest or during physical activity.

MATTER

Chemistry is the science that studies the structure and composition of matter: the solids, liquids, and gases that are the basic building blocks of our universe. *Matter is defined as a substance (composed of atoms or molecules, or a mixture of the two) that occupies space and has mass.* All the biologic substances in the body are matter, and thus all of these substances have mass. A fundamental property of all matter is inertia, the resistance to change in speed or position when a force is applied. We clearly observe this resistance to movement when we try to move something heavy.

Mass

The mass of an object is the quantitative measure of its inertia or resistance to acceleration. Under ordinary circumstances, the mass of any object remains constant whether it is submerged under water or is nearly weightless beyond the earth's atmosphere. The greater the mass, the larger its inertia and the smaller the change produced when a force is applied.

Weight

The term weight is often used interchangeably (but imprecisely) to mean the same as mass; weight is related to mass but is not identical to it. *The weight of an object is equal to its mass and the gravitational attraction by the earth or other celestial body.* On earth, where gravitational force is fairly constant, differences between individuals in body weight are due to differences in body mass. On the surface of the moon, in contrast, with a smaller gravitational force, a person would weigh only one-sixth as much, yet the person's mass would remain unchanged. Even on earth, the weight of an object is slightly more at the South Pole (more gravitational pull) than at the Equator (less gravitational pull). Although the weight of an object changes according to where it is located, its mass remains the same. So, if you want to be precise, the next time you weigh yourself, remember that what you have measured is your mass and the attractive or gravitational force the earth exerts on this mass.

Density

Matter takes up space and occupies a volume. *The mass of a unit volume of a material substance is referred to as its density.* This is computed by the equation: density = mass ÷ volume, and is usually expressed as grams per cubic centimeter (g/cc). In nutrition studies, the physical density of a food is determined by its mass in relation to the volume it occupies. For example, the density of a fatty food is less than that of a food composed mostly of protein or carbohydrate (yet as we will see in Chapter 7, the caloric or "energy density" of the fat-laden food is nearly twice as high!).

The metric system. Scientific measurement is generally presented in terms of the metric system. This system uses units that are related to each other by the power of ten. The prefix centi- means one-hundredth, milli- means one thousandth, and the prefix kilo- is also derived from a word that means one thousand. Consequently, 1 kilogram (kg) is 1000 grams (g) or 2.2 pounds (lb). In general, we will use metric units throughout the text, although the English system will also appear where applicable.

Why does one person sink and the other float?

High turnover rate of some elements. The mineral content of the body does not remain fixed. Some elements are continually replaced. During the growth cycle, for example, the mineral calcium is in a continual state of flux; more calcium is used than is excreted. Thus, there is a large turnover in bone during the first year of life. During adolescence, up to 32% of the skeletal mass per year can be rebuilt.

How elements are named. Each of the elements is abbreviatd by a one- or two-letter atomic symbol, a practice first used by the Swedish chemist Jons Berzelius in the early 1800s. Twelve elements are identified by the first letter of their name; most of the others are identified by the first two letters. In several cases the atomic symbol is derived from the Latin name for the element: Fe stands for iron (Latin *ferrum*), Pb for lead (Latin *plumbum*), Ag for silver (Latin *argentum*), and Na, the shorthand term for sodium, is from the Latin *natrium*.

The concept of density is also relevant when considering human body composition. For example, although two people may have the same body mass, their proportion of fat to muscle could differ radically. One person's fat content, for example, could be 38% of total mass, whereas the second person could possess one-tenth the fat, or only 3.8% of body mass. Because fat and muscle occupy different volumes per unit mass (i.e., they possess different densities), the volume occupied by each person varies considerably, depending on individual differences in body composition, even though body mass may be identical. Chapter 16 focuses on the concept of body density in relation to body fat content.

ELEMENTS

Matter in the universe is composed of fundamental materials called elements. Of the 105 elements which have been identified, 90 occur in nature, either free or in combination with other elements; the remaining 15 are produced artificially. *An important characteristic of an element is that it cannot be decomposed into a simpler substance by ordinary chemical processes.* Water, for example, is not an element because it can be chemically separated into the elements hydrogen and oxygen. As you will see in Chapter 6, minerals are the fundamental elements required by the body for optimal functioning.

Distribution of Elements in the Body. In humans, the most abundant elements are oxygen (O; 65%), carbon (C; 18%), hydrogen (H; 10%), and nitrogen (N; 3%). Combined, their composition by weight, shown in Figure 1-1, constitutes approximately 96% of body mass. These elements serve as the chief constituents of five of the six nutrients — carbohydrates, lipids, proteins, vitamins, and water — and comprise the structural units for most biologically active substances in the body. The remaining group of mineral nutrients includes major minerals such as the elements calcium (1.5%), phosphorus (1.0%), potassium (0.4%), sulfur (0.3%), sodium and chlorine (0.2%), and magnesium as well as such exotic elements as vanadium, gold, silver, silicon, molybdenum, manganese, copper, cobalt, selenium, chromium, tin, and even arsenic. These elements are present in the body only in trace amounts, usually as integral parts of protein catalysts or enzymes (see "Enzymes" in this chapter). For example, copper (Cu) forms part of the enzymes associated with absorption and metabolism of the mineral iron. Copper is also intimately involved in the release of cholesterol from the liver; it helps to clot blood and, when bound to certain enzymes, aids in the synthesis of important neurotransmitters.

CELLULAR ORGANIZATION

Many types of cells make up biologic systems. The basic processes that sustain life among all cells are fairly similar, even though different cells carry out unique functions that necessitate special structures. Cells with different functions also contain essentially the same chemicals; they differ only in the proportion and arrangement of these chemicals. Figure 1-2 shows the complexity of the body's biologic organization. Humans are composed of a collection of diverse systems, each with highly specialized organs and tissues. The tissues are composed of many cells, and the cells are made up of molecules. Molecules, in turn, are constructed from individual atoms.

Organs

The body is a collection of eleven organ systems: the digestive, urinary, nervous, integumentary, skeletal,

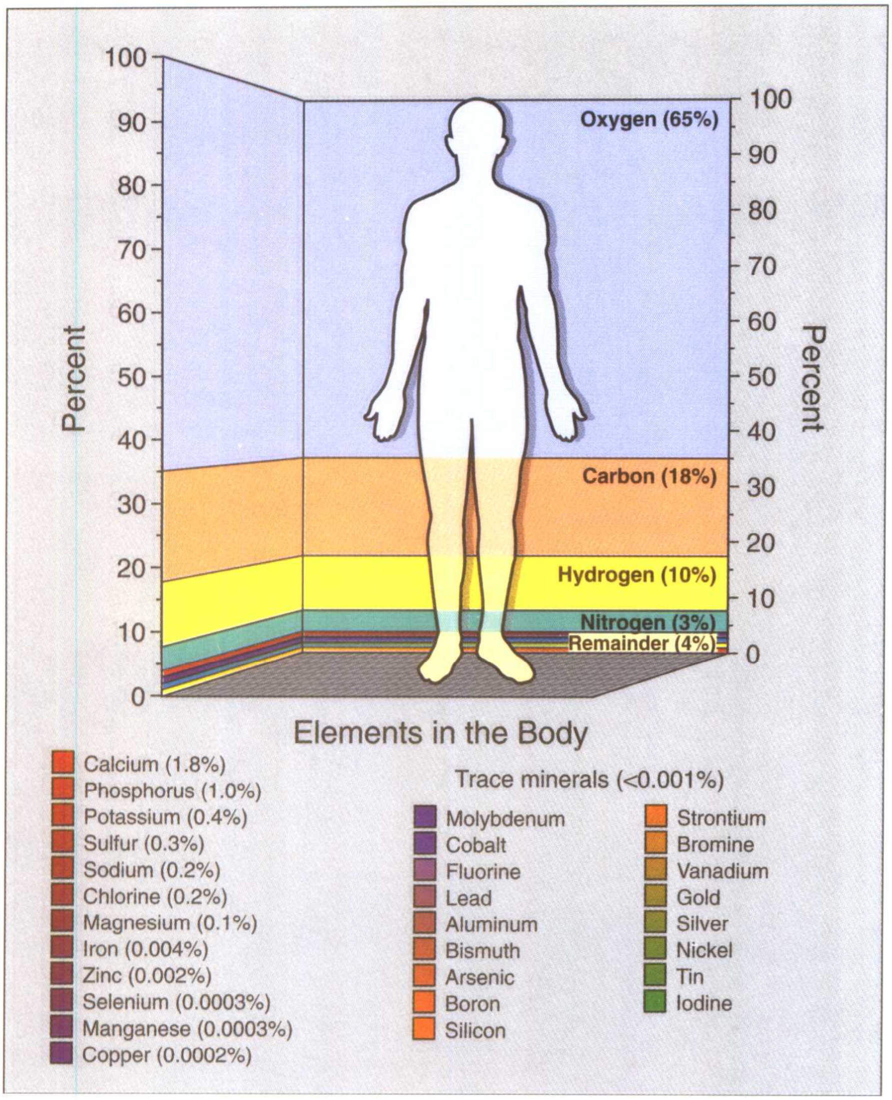


Figure 1-1. Elemental composition of the human body. The percentages represent the approximate contribution of the elements to the body mass of a typical 60 kg person.

muscular, endocrine, pulmonary, lymphatic, reproductive, and cardiovascular. In turn, each organ system is made up of combinations of specialized tissues joined together to perform a common function. For example, specific cells make up the three main components of the integumentary system: the skin, hair, and nails. This system forms the body's outer protective layer to shield the deeper tissues from injury or invasion by outside organisms, as well as to respond to stimuli evoked by pressure, temperature, and pain. The skin also is the formation site of vitamin D. All the organ systems have their own particular and unique functions, yet each usually works in harmony with the others to maintain an optimal state of bodily function.

Cells

Below the level of the organ systems are the cells. *Cells represent the basic units of life;* they vary in size and shape depending on their specific function. Most have a diameter of approximately 10 micrometers (a micrometer, or μm, is 1/1000 of an inch), but an egg or ovum cell can be as large as 140 μm in diameter. Cell length can also vary tremendously, from approximately 8 μm for red blood cells, to a muscle cell 30 cm long, or a nerve cell that stretches up to 1 meter (100 cm) in length!

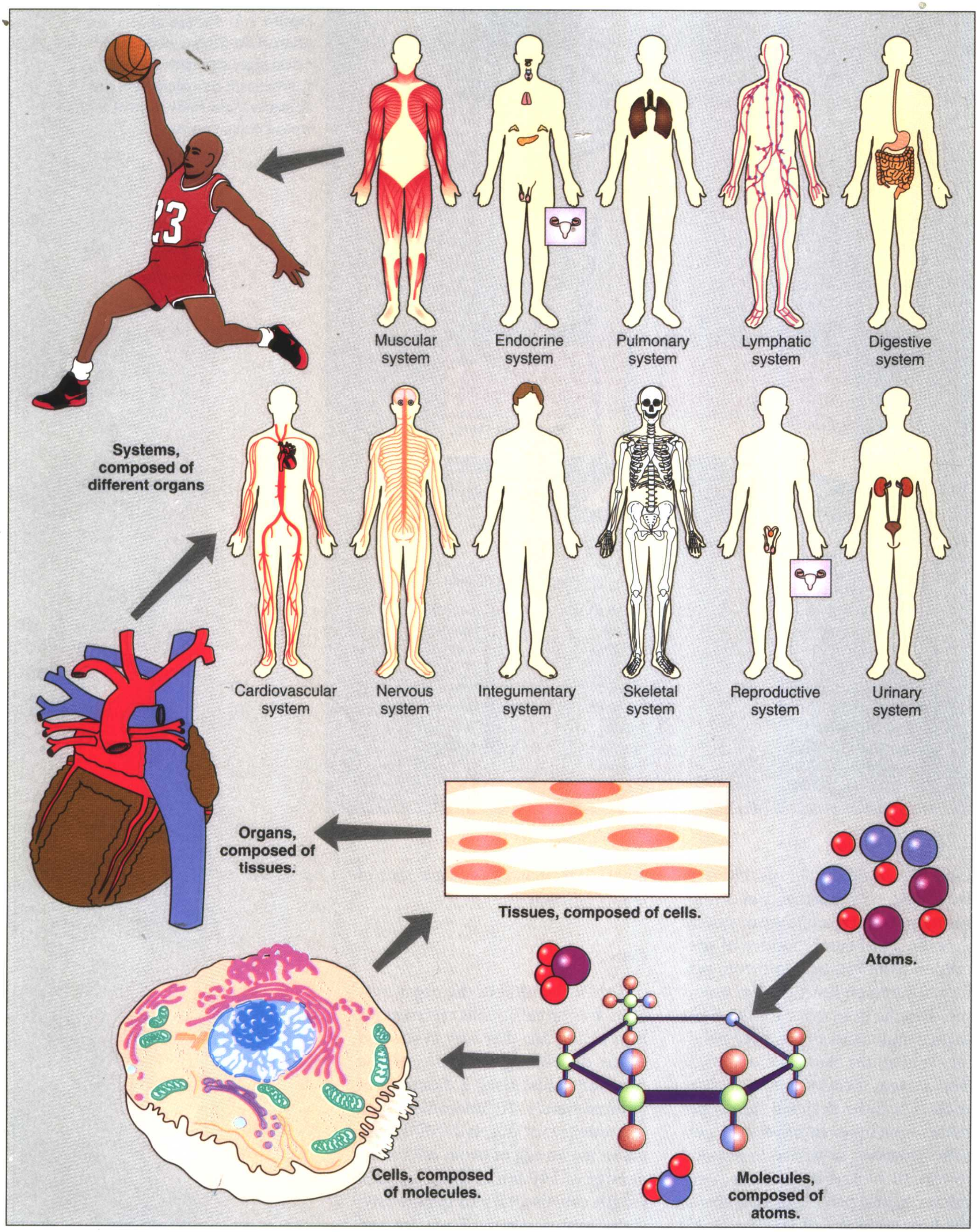


Figure 1-2. Atoms, molecules, cells, tissues, organs, and organ systems represent the body's increasingly more complex level of biologic organization.

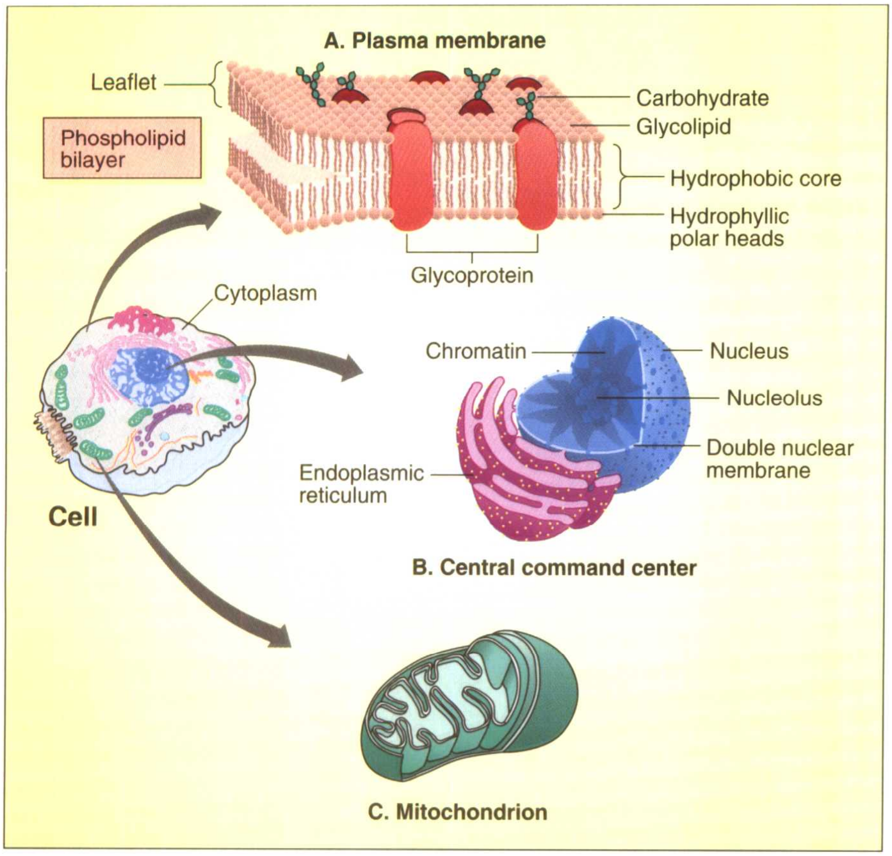


Figure 1-3. Three characteristic structures of living cells. *A.* The *plasma membrane*, a double "sandwich-type" structure composed of lipids (mostly phospholipids) and interspersed with proteins. Note that the bilayer can be split into two halves or leaflets. Each leaflet is responsible for binding specific protein structures. An elaborate network of tubules and microchannels serves as "inner scaffolding" to provide structure for the gel-like contents of the cell. *B.* The central command system, the *nucleus,* is the largest structure in the cell and regulates its many functions. Note that the endoplasmic reticulum joins the double nuclear membrane and is continuous with it. *C. Mitochondria,* the cell's "powerhouses", convert food nutrients into useful energy during aerobic metabolism. The size and number of mitochondria, as well as the enzymes that regulate energy metabolism, increase significantly with endurance training.

The Shape of Cells also Differs. The red blood cell is both oval (and thus adapted for carrying oxygen and carbon dioxide) and flat (for rapid uptake or release of these gases in appropriate tissues). Some digestive cells have many convolutions and depressions to increase their surface area-to-volume ratio and permit greater absorption of nutrients through their membranes. The epithelial cells on the inside of the mouth are flat and tightly packed to protect the underlying tissues from penetration by bacteria.

Although unique and often highly specific in function, cells share many structures in common. Figure 1-3 illustrates three common characteristics of living cells:

- *A plasma membrane,* a "sandwich-type" double structure made of lipids and proteins, separates the cell's contents from the surrounding extracellular fluid. The cell membrane is semipermeable, so only materials of certain sizes can be exchanged between the cell and its environment. The bilayer serves as the basic constituent of the membrane; the core of the bilayer contains the fatty acid "tails" of the phospholipid, and the inner portion of the membrane prevents water-containing molecules from simply passing through the membrane. This part of the membrane is said to be *hydrophobic* (water-fearing). The outside of the bilayer membrane contains the polar "heads" of the phospholipid molecule. This part of the membrane is *hydrophilic* (water-loving); it is in continual contact with water on both the inside and outside of the cell.
- A central command center, the *nucleus,* is the largest structure in the cell and regulates its many functions. The nucleus contains chromatin, a precursor of the chromosomes that carry the hereditary material. The deoxyribonucleic acid (DNA) of the chromosomes directs cellular protein synthesis; ribonucleic

DNA. DNA is a highly specialized series of molecules called nucleic acids that exist in all cell nuclei. Nucleic acids code, store, and transmit the character of inherited traits of the organism through generations.