LEARNING MADE EASY

3rd Edition

Biochemistry

for dummies®
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Grasp the basics of biochemistry

Understand the microscopic details of life

Explore DNA replication

John T. Moore, EdD

Richard H. Langley, PhD

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3rd Edition

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Contents at a Glance

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Introduction

Welcome to the third edition of *Biochemistry For Dummies!* We're certainly happy you've decided to delve into the fascinating world of biochemistry. Biochemistry is a complex area of chemistry, but understanding biochemistry isn't really complex. It takes hard work, attention to detail, and the desire to know and to imagine. Biochemistry, like any area of chemistry, isn't a spectator sport. You must interact with the material, try different explanations, and ask yourself why things happen the way they do.

If you work hard, you can get through your biochem course. More important, you may grow to appreciate the symphony of chemical reactions that take place within a living organism, whether it's a one-celled organism, a tree, or a person. Just like each individual instrument contributes to an orchestra, each chemical reaction in an organism is necessary, and sometimes its part is quite complex. However, when you combine all the instruments and each instrument functions well, the result can be a wonder to behold. If one or two instruments are a little out of tune or aren't played well, the orchestra still functions, but things are a little off. The sound isn't quite as beautiful as it might be, or the listener might have a nagging sensation of something being wrong. The same is true of an organism. If all the reactions occur correctly at the right time, the organism functions well. If a reaction or a few reactions are off in some way, the organism may not function nearly as well. Genetic diseases, electrolyte imbalance, and other problems may cause the organism to falter. And what happens then? Biochemistry is often the field in which researchers find ways of restoring the organism to health and seek cures for many modern medical maladies.

About This Book

Biochemistry For Dummies is an overview of the material covered in a typical college-level biochemistry course. In this third edition, we update the content and correct the errors and omissions that crept into the first two editions. We hope that this edition is of even more help than the second. We've made every attempt to keep the material as current as possible, but the field is changing ever so quickly. The basics, however, stay the same, and that's where we concentrate our efforts. We also include information on some of the applications of biochemistry that you read about in your everyday life, such as forensics, cloning, gene therapy, genetic testing, and genetically modified foods.

We've organized the text in a logical progression of topics that may be used in a biochemistry course. Along the way, we use the following conventions to make the presentation of information consistent and easy to understand:

- When we introduce new terms, they appear in *italics.*
- We use **bold text** to highlight keywords in bulleted lists.

We also make extensive use of structures and reactions. While reading, try to follow along with the associated figures.

While you flip through this book, you can see a lot of chemical structures and reactions. Much of biochemistry revolves around knowing the structures of the molecules involved in biochemical reactions. Function follows form. If you're in a biochemistry course, you've probably had at least one semester of organic chemistry. You might recognize many of the structures, or at least the functional groups, from your study of organic chem. You can see many of those mechanisms that you loved (and hated) here in biochemistry.

If you're taking a biochemistry course, use this rather inexpensive book to supplement that very expensive biochemistry textbook. If you bought this book to gain general knowledge about a fascinating subject, try not to get bogged down in the details. Skim the chapters. If you find a topic that interests you, stop and dive in. Have fun learning something new. You don't have a whole lot of money invested in this book, so don't feel obligated to read everything. When you're done, you can put it on your bookshelf alongside *Chemistry For Dummies*, *The Doctor Who Error Finder*, and *A Brief History of Time* as a conversation piece.

Foolish Assumptions

We assume — and we all know about the perils of assumptions — that you're one of the following:

- A student taking a college-level biochemistry course
- A student reviewing your biochemistry for some type of standardized exam (the MCAT, for example)

- An individual who wants to know something about biochemistry
- A person who's been watching way too many forensic TV shows

If you fall into a different category, we hope you enjoy this book anyway.

Icons Used in This Book

If you ever read a *For Dummies* book before (such as the wonderful *Chemistry For Dummies*, by one of this book's authors, John T. Moore), you can recognize most of the icons used in this book, but here are their meanings anyway:

REAL WORLD

The Real World icon points out information that has a direct application in the everyday world. These paragraphs may also help you understand the bigger picture of how and why biochemical mechanisms are in place.

REMEMBER

This icon is a flag for those really important points that you shouldn't forget while you go deeper into the world of biochemistry.

TIP

We use this icon to alert you to a tip on the easiest or quickest way to learn a concept. Between the two of us, we have almost 70 years of teaching experience. We've learned a few tricks along the way, and we don't mind sharing.

WARNING

The Warning icon points to a procedure or potential outcome that can be dangerous. We call it our Don't-Try-This-At-Home icon.

Beyond the Book

As if this book wasn't already chock full of helpful information, we provide you with a handy online Cheat Sheet that includes basic biochemical structures and genetic patterns. To access this Cheat Sheet, simply go to `www.dummies.com` and type **Biochemistry For Dummies Cheat Sheet** in the search box.

Where to Go from Here

The answer to where you should start really depends on your prior knowledge and goals. Like with all *For Dummies* books, this one attempts to make all the chapters discrete so that you can pick a chapter that contains material you're having difficulty with and get after it, without having to read other chapters first. If you feel comfortable with the topics covered in general and organic chemistry, feel free to skip Part I. If you want a general overview of biochemistry, skim the remainder of the book. Dive deeper into the gene pool when you find a topic that interests you.

And for all of you, no matter who you are or why you're reading this book, we hope that you have fun reading it and that it helps you increase your understanding of biochemistry.

1

Setting the Stage: Basic Biochemistry Concepts

IN THIS PART . . .

Getting to know biochemistry and its relationship to other disciplines within chemistry and biology

Diving into water chemistry, including pH and buffers

Brushing up on organic chemistry

IN THIS CHAPTER

» **Understanding the importance of biochemistry**

» **Looking at the parts and functions of animal cells**

» **Seeing the differences between animal and plant cells**

Chapter 1

Biochemistry: What You Need to Know and Why

If you're enrolled in a biochemistry course, you may want to skip this chapter and go right to the specific chapter(s) in which we discuss the material you're having trouble with. But if you're thinking about taking a course in biochemistry or just want to explore an area that you know little about, keep reading. This chapter gives you basic information about cell types and cell parts, which are extremely important in biochemistry.

Sometimes you can get lost in the technical stuff and forget about the big picture. This chapter sets the stage for the details.

Why Biochemistry?

We suppose the flippant answer to the question "Why biochemistry?" is "Why not?" or "Because it's required."

That first response isn't a bad answer, actually. Look around. See all the living or once living things around you? The processes that allow them to grow, multiply, age, and die are all biochemical in nature. Sometimes we sit back and marvel at the complexity of life, fascinated by the myriad chemical reactions that are taking place right now within our own bodies and the ways in which these biochemical reactions work together so we can sit and contemplate them.

When John learned about the minor structural difference between starch and cellulose, he remembers thinking, "Just that little difference in the one linkage between those units is basically the difference between a potato and a tree." That fact made him want to learn more, to delve into the complexity of the chemistry of living things, to try to understand. We encourage you to step back from the details occasionally and marvel at the complexity and beauty of life.

What Is Biochemistry and Where Does It Take Place?

Biochemistry is the chemistry of living organisms. Biochemists study the chemical reactions that occur at the molecular level of organisms. Biochemistry is normally listed as a separate field of chemistry. However, in some schools it's part of biology, and in others it's separate from both chemistry and biology.

Biochemistry really combines aspects of all the fields of chemistry. Because carbon is the element of life, *organic chemistry* (the study of carbon-based compounds) plays a large part in biochemistry. Many times, biochemists study how fast reactions occur — that's an example of *physical chemistry.* Often, metals are incorporated into biochemical structures (such as iron in hemoglobin) — that's *inorganic chemistry.* Biochemists use sophisticated instrumentation to determine amounts and structures — that's *analytical chemistry.* And biochemistry is also similar to *molecular biology;* both fields study living systems at the molecular level, but biochemists concentrate on the chemical reactions that occur.

Biochemists may study individual electron transport within the cell, or they may study the processes involved in digestion. If it's alive, biochemists study it.

Types of Living Cells

All living organisms contain cells. A *cell* is not unlike a prison cell. The working apparatus of the cell is imprisoned within the bars — known as the *cell membrane.* Just as a prison inmate can still communicate with the outside world, so can the cell's contents. The prisoner must be fed, so nutrients must be able to enter every living cell. The cell has a sanitary system for the elimination of waste. And, just as inmates may work to provide materials for society outside the prison, a cell may produce materials for life outside the cell.

Cells come in two types: prokaryotes and eukaryotes. (Viruses also bear some similarities to cells, but these similarities are limited. In fact, many scientists don't consider viruses to be living things.) Prokaryotic cells are the simplest type of cells. Many one-celled organisms are prokaryotes.

TIP

The simplest way to distinguish between these two types of cells is that a *prokaryotic cell* contains no well-defined nucleus, whereas the opposite is true for a *eukaryotic cell.*

Prokaryotes

Prokaryotes are mostly bacteria. Besides the lack of a nucleus, a prokaryotic cell has few well-defined structures. The prison cell's structure has three components: a cell wall, an outer membrane, and a plasma membrane. This structure allows a controlled passage of material into and out of the cell. The materials necessary for proper functioning of the cell float about inside it, in a soup known as the *cytoplasm.* Figure 1-1 depicts a simplified version of a prokaryotic cell.

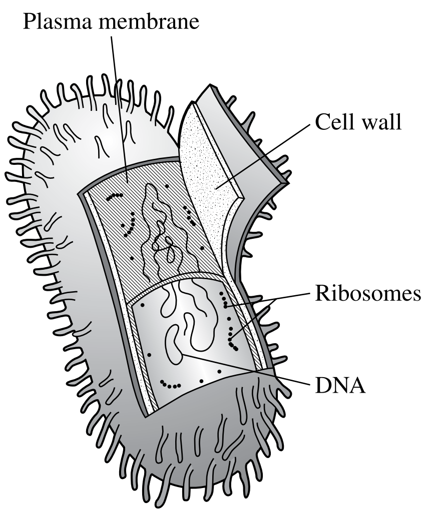

FIGURE 1-1: Simplified prokaryotic cell.

Eukaryotes

Eukaryotes are animals, plants, fungi, and *protists* (any organism that isn't a plant, animal, or fungus). Many are unicellular organisms, like most algae, while other types of algae are multicellular. You consist mostly of eukaryote cells. In addition to having a nucleus, eukaryotic cells have a number of membrane-enclosed components known as *organelles.* Eukaryotic organisms may be either unicellular or multicellular. In general, eukaryotic cells contain much more genetic material than prokaryotic cells.

Animal Cells and How They Work

All animal cells (which, as the preceding section explains, are eukaryotic cells) have a number of components, most of which are considered to be organelles. These components, and a few others, are also present in plant cells (see the section "A Brief Look at Plant Cells," later in this chapter). Figure 1-2 illustrates a simplified animal cell.

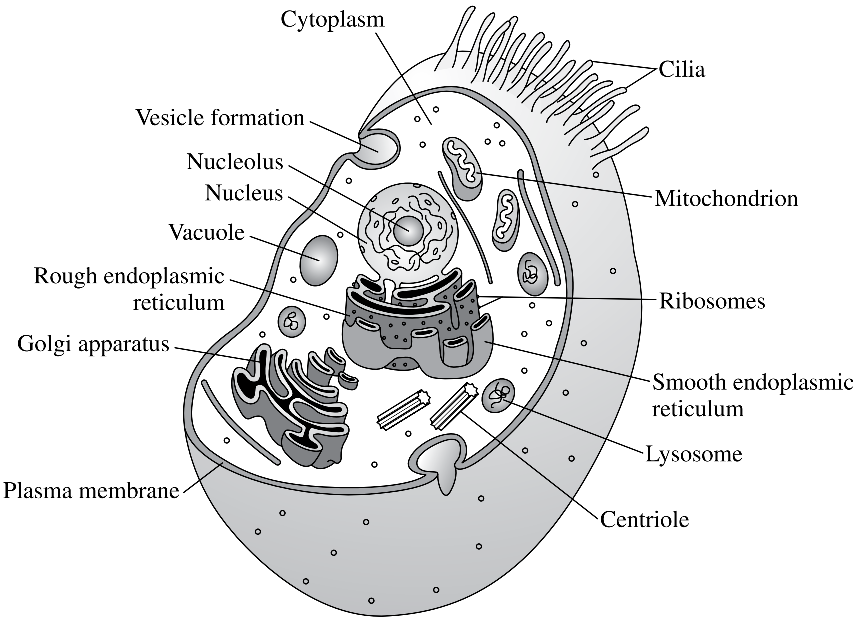

FIGURE 1-2: Simplified illustration of an animal cell.

The primary components of animal cells include

- **Plasma membrane:** This structure separates the material inside the cell from everything outside the cell. The *plasma* or *cytoplasm* is the fluid inside the cell. For the sake of the cell's health, this fluid shouldn't leak out. However, necessary materials must be able to enter through the membrane, and other materials, including waste, must be able to exit through the membrane. (Imagine what a cesspool that cell would become if the waste products couldn't get out!)

REMEMBER

Transport through the membrane may be active or passive. *Active transport* requires that a price be paid for a ticket to enter (or leave) the cell. The cost of the ticket is energy. *Passive transport* doesn't require a ticket. Passive transport methods include *diffusion, osmosis,* and *filtration.*

- **Centrioles:** These structures behave as the cell's train conductors. They organize structural components of the cell like *microtubules,* which help move the cell's parts during cell division.
- **Endoplasmic reticulum:** The cell can be thought of as a smoothly running factory. The *endoplasmic reticulum* is the main part of the cell factory. This structure has two basic regions, known as the *rough* endoplasmic reticulum (the factory assembly line for protein production), which contains *ribosomes,* and the *smooth* endoplasmic reticulum, which does not. (You can find out more about ribosomes and their function later in this list.) The rough endoplasmic reticulum, through the ribosomes, is the factory's assembly line. The smooth endoplasmic reticulum is more like the shipping department, which ships the products of the reactions that occur within the cell to the Golgi apparatus.
- **Golgi apparatus:** This structure serves as the cell's postal system. It looks a bit like a maze, and within it, materials produced by the cell are packaged in *vesicles* — small, membrane-enclosed sacs. The vesicles are then mailed to other organelles or to the cell membrane for export. The cell membrane contains customs officers (called *channels*) that allow secretion of the contents from the cell. Secreted substances are then available for other cells or organs.
- **Lysosomes:** These are the cell's landfills. They contain digestive enzymes that break down substances that may harm the cell (Chapter 6 has a lot more about enzymes). The products of this digestion may then safely move out of the lysosomes and back into the cell. Lysosomes also digest no-longer functioning (dead) organelles. This slightly disturbing process, called *autodigestion,* is really part of the cell digesting itself. (We've never gotten *that* hungry!)
- **Mitochondria:** These structures are the cell's power plants, where the cell produces energy. Mitochondria (singular *mitochondrion*) use food, primarily the carbohydrate *glucose,* to produce energy, which comes mainly from breaking down *adenosine triphosphate* (or ATP, to which we have dedicated Chapter 13).

- **Nucleus/nucleolus:** Each cell has a *nucleus* and, inside it, a *nucleolus.* These two regions serve as the cell's control center and are the root from which all future generations originate. A double layer known as the *nuclear membrane* surrounds the nucleus. Usually the nucleus contains a mass of material called *chromatin.* If the cell is entering a stage leading to reproducing itself through cell division, the chromatin separates into *chromosomes.*

  In addition to conveying genetic information to future generations, the nucleus produces two important molecules for the interpretation of this information. These molecules are *messenger ribonucleic acid* (mRNA) and *transfer ribonucleic acid* (tRNA). The nucleolus produces a third type of ribonucleic acid known as *ribosomal ribonucleic acid* (rRNA). (Chapter 9 is all about nucleic acids.)
- **Ribosomes:** These components contain protein and ribonucleic acid subunits. In the ribosomes, amino acids are assembled into *proteins.* Many of these proteins are enzymes, which are part of nearly every process that occurs in the organism. (Part II of this book is devoted to amino acids, proteins, and enzymes.)
- **Small vacuoles:** Also known as simply *vacuoles,* these structures serve a variety of functions, including storage and transport of materials. The cell may later use these stored materials, or if the cell no longer needs these materials, they are simply waste.

A Brief Look at Plant Cells

Plant cells contain the same components as animal cells, plus a cell wall, a large vacuole, and, in the case of green plants, chloroplasts. Figure 1-3 illustrates a typical plant cell.

The *cell wall* is composed of cellulose. *Cellulose*, like starch, is a polymer of glucose. The cell wall provides structure and rigidity.

The *large vacuole* serves as a warehouse for large starch molecules. Glucose, which is produced by photosynthesis, is converted to *starch*, a polymer of glucose. At some later time, this starch is available as an energy source. (Chapter 7 talks a lot more about glucose and other carbohydrates.)

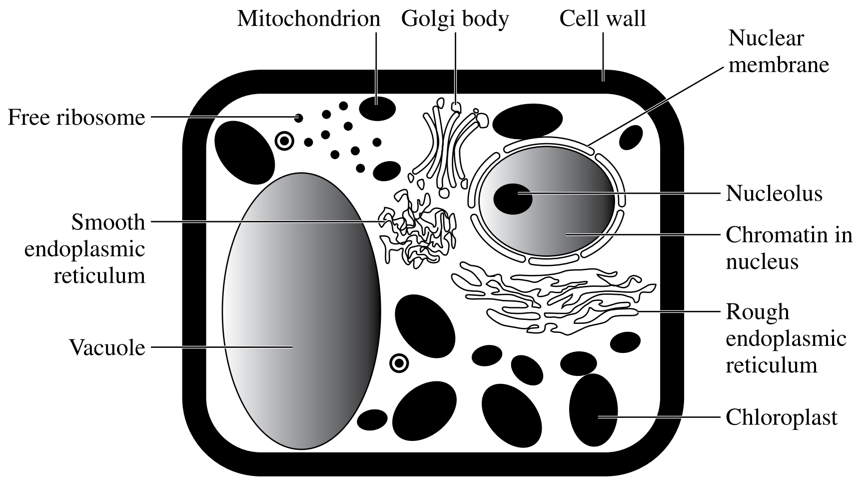

FIGURE 1-3: Simplified illustration of a plant cell.

Chloroplasts, present in green plants, are specialized chemical factories. These are the sites of *photosynthesis*, in which *chlorophyll* absorbs sunlight and uses this energy to combine carbon dioxide and water to produce glucose and release oxygen gas.

The green color of many plant leaves is due to the magnesium-containing compound chlorophyll.

IN THIS CHAPTER

» Understanding the roles and properties of water

» Exploring the differences between acids and bases

» Controlling pH with buffers

Chapter 2

Seems So Basic: Water Chemistry and pH

Water is one of the most important substances on Earth. People swim, bathe, boat, and fish in it. It carries waste from people's homes and is used in the generation of electrical power. Humans drink it in a variety of forms: pure water, soft drinks, tea, coffee, beer, and so on. Water, in one form or another, moderates the temperature of the Earth and of the human body.

In the area of biochemistry, water is also one of the lead actors. The human body is about 70 percent water. Water plays a role in the transport of material to and from cells. And many, many aqueous solutions take part in the biochemical reactions in the body.

In this chapter, we examine the water molecule's structure and properties. We explain how water behaves as a solvent. We also look at the properties of acids and bases, and the equilibria that they may undergo. Finally, we discuss the pH scale and buffers, including the infamous Henderson-Hasselbalch equation. So sit back, grab a glass of water (or your favorite water-based beverage), and dive in!

The Fundamentals of H_2O

Water is essential to life; in fact, human beings are essentially big sacks of water. Water accounts for 60 to 95 percent of living human cells, and 55 percent of the water in the human body is in intracellular fluids. The remaining 45 percent (extracellular) is divided among the following:

- Plasma (8 percent)
- Interstitial (between cells) and lymph (22 percent)
- Connective tissue, cartilage, and bone (15 percent)

Water also is necessary as a solvent for the multitude of biochemical reactions that occur in the body:

- Water acts as a transport medium across membranes, carrying substances into and out of cells.
- Water helps maintain body temperature.
- Water acts as a solvent (carrying dissolved chemicals) in the digestive and waste excretion systems.

Healthy humans have an intake/loss of about 2 liters of water per day. The intake is about 45 percent from liquids and 40 percent from food, with the remainder coming from the oxidation of food. The loss is about 50 percent from urine and 5 percent from feces, with the remainder leaving through evaporation from the skin and lungs. A water balance must be maintained within the body. If the water loss significantly exceeds the intake, the body experiences dehydration. If the intake significantly exceeds the water loss, water builds up in the body and causes *edema* (fluid retention in tissues).

In the following sections, we touch on the basic properties of this must-have liquid, as well as its most important biochemical function.

Let's get wet! The physical properties of water

The medium in which biological systems operate is water, and the physical properties of water influence the biological systems. Therefore, it's important to review some water properties from general chemistry.