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Biophysics FOR DUMMIES®

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Learn to:

- Make sense of complicated formulas
- Grasp the practical applications of biophysics
- Understand the connection between the life sciences and physics
- Perform better in your biophysics course

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FOR DUMMIES
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Contents at a Glance

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Introduction

Welcome to *Biophysics For Dummies.* Biophysics is a fascinating field of science that combines the study of the laws of physics with the study of systems involving living organisms (biology). The combination of these two fields makes biophysics interdisciplinary, which means biophysicists work side by side with people from many different backgrounds. Biophysics is a very diverse and interesting field; even if you spend your entire life studying biophysics, you can still discover new and interesting pieces of information.

About This Book

Biophysics For Dummies lays down the foundations for the fields of biophysics, including neurophysics, medical physics, health physics, and related fields that overlap with biophysics, presented in an easy-to-access manner. This reference book presents biophysics in plain English, so you can easily find what you're looking for. When you're reading, you don't have to begin at the beginning. You can go directly to the chapter or section that interests you and start reading. Of course, I prefer that you read it from cover to cover, but then again, I am a bit biased. If you're strapped for time and only want to read what you need to know, even when you're reading the chapter or section of interest to you, you can skip the sidebars and the paragraphs marked with the Technical Stuff icon without losing any of the essential info.

This book is unique in that the majority of the material is at the introductory level, but the material presented is at an advanced enough level that you can use the book as a stepping stone in your biophysics studies. This book also lays out in a clear step-by-step procedure how to apply concepts in physics to problems in biophysics and the life sciences. The book introduces topics in the five fundamental areas of physics: mechanics, fluids, thermodynamics, electromagnetism, and nuclear physics.

You may notice while reading the book that I have done a few things that I hope make your reading and search of information easier:

- I avoid using URLs. These URLs can change over time, so I have placed only the more important ones that probably won't change on the online Cheat Sheet. You can find all the important links in a single place for easy access with a single click at `www.dummies.com/cheatsheet/biophysics`.
- I italicize all the variables used in mathematical formulas, so you can easily identify them. I also italicize words when I define them. Many words in biophysics have special meanings, and understanding the terminology is an important step toward comprehending the subject.
- I use certain symbols differently than do some other biophysics books. The symbols are as follows:
  - N for the torque instead of τ (*tau*), which is used in many introductory books. (Many engineering books use M.) Some more advanced physics books use N for torque and in addition, τ looks very similar to t (time), T (period), and T (half-life). I would have too many physical quantities using similar symbols.
  - $P^{(a)}$ for absolute pressure, $P^{(g)}$ for gauge pressure, and P for power. I have too many sections where I use power and pressure at the same time, so I distinguish them this way.
  - E represents energy and F represents force. I distinguish between the different energies and forces by using subscripts. Some books use T or K for the kinetic energy and some use U or V for the potential energy. I use E_K and E_P instead for kinetic energy and potential energy.

Foolish Assumptions

As I write this book, I assume you, my dear reader, fall into at least one of the following groups:

- You're in college and taking an introductory biophysics course.
- You're interested in studying biophysics or some related field where knowledge of biophysics is useful.
- You're involved with the sciences and want to expand your knowledge base in biophysics.
- You have already taken algebra, geometry, and a science course in either biology, chemistry, or physics.

Icons Used in This Book

I use a few icons as markers in the margins. These markers are useful for helping you locate material or skip over material, depending on what you're searching for. I use them to indicate what I think is important for you to notice. These icons can help you navigate through the material.

When I present helpful information that can make your life a bit easier when studying biophysics, I use this icon.

This icon highlights important pieces of information that I suggest you store away because you'll probably use them on a regular basis.

This icon highlights common mistakes or errors that I see time after time from people who are taking a biophysics course.

This icon indicates in-depth examples. Try solving the problem and continue reading to see how to solve the problem.

This icon requires nonessential information, usually at least at a calculus background level. If you have a math phobia, then you may want to avoid reading these paragraphs. If you enjoy biophysics and mathematics, then I encourage you to read these paragraphs.

Beyond This Book

In addition to the material in *Biophysics For Dummies,* I also provide a free Cheat Sheet online at `www.dummies.com/cheatsheet/biophysics`. The Cheat Sheet adds a few extra tidbits that you will find interesting, such as solving biomechanical problems. You can also find other interesting bits of additional information online at `www.dummies.com/extras/biophysics`.

After reading the Cheat Sheet and online information, you may decide to pursue biophysics more in-depth, so I include URLs to the biophysical society, the association of medical physicists, and the health physics society. These links are a great starting point in search of answers to your biophysical questions.

Where to Go from Here

Science is about being curious and exploring, which is what attracted me to biophysics. As you read this book, feel free to jump around and start with the chapters and sections that interest you the most. If you need a particular section for your science course, such as kinematics or biomechanics, you can go straight there. You can also look in the index or the table of contents to find a topic that interests you. No matter what you decide to read, enjoy your adventure into the world of biophysics.

Part I

Getting Started with Biophysics

web extras

Go to `www.dummies.com/cheatsheet/biophysics` to discover some more informative Dummies content online about biophysics.

In this part . . .

- Get a thorough overview of what biophysics is, including its diverse fields, such as biomechanics, fluids, waves and sound, the electromagnetic force, and medical physics, so you can fully appreciate how it affects your daily life.
- Discover where you can find biophysics. You may be surprised to know who biophysicists are and where biophysics is used.
- Tackle mathematics, most of which should be a review for you if you've already taken a chemistry, physics, or calculus class. Biophysics does use mathematics, so having a decent grasp of the basic formulas and equations is important when you study biophysics.
- Comprehend some of the basics of biophysics, such as notation and terminology, that aren't used in everyday life and clear up a few common myths.
- Make the distinction between experimental and theoretical biophysics. Biophysics isn't mathematics, but mathematics is a tool used by both experimental and theoretical biophysicists.

Chapter 1

Welcoming You to the World of Biophysics

In This Chapter

- Mentioning mechanics
- Flowing with fluids
- Riding the waves
- Identifying biophysics in the every day

Biophysics is the study of biology and all sciences connected to the biological sciences using the principles and laws of physics. It's the ultimate interdisciplinary science combining biology, chemistry, and physics. If you love science, then biophysics is for you. The field touches on all aspects of all the natural sciences.

This chapter gives you the bird's-eye view of biophysics and what you'll find in this book. In this chapter, I explain the general features of biomechanics, the motion of fluids, waves and sounds, and electromagnetic force as well as radiation and radioactivity.

Getting the Lowdown on What Biophysics Really Is

No matter if you're stuck taking a biophysics course to meet your science course requirements or you're taking your first of many biophysics courses, you need to make sure you understand what you're studying. Just break down the word *biophysics. Bio* means life and *physics* means nature, so biophysics is the study of living matter, its motion, and its interaction with the natural universe. Chapter 2 expands on the explanation of what biophysics is, and Chapter 3 covers some of the basic terminology used in biophysics.

The following clarifies what biophysics really means:

- Biophysics uses techniques and methods from physics, mathematics, biology, and chemistry to study living organisms.
- Biophysicists design experiments or do computational calculations in order to understand biological processes. A few examples of these biological processes are
    - Photosynthesis
    - The on-off switching of genes
    - Memory and brain processes
    - Muscle control
- Biophysicists study how the senses work.
- Biophysicists try to understand why things behave the way they do in sports and improve the performance of athletes.
- Biophysicists study how molecules enter cells and how they interact.
- Biophysicists study how cells move, divide, and respond to the environment.

As you can see, biophysics is all of this and everything that deals with living organisms. Biophysics plays an essential role in medicine, sports, engineering, physics, biology, biochemistry, and environmental science to mention a few areas. Whenever you're considering something that involves a living organism and its interaction with its surroundings, you're using biophysics.

Grasping the Mechanics of Biomechanics

Biomechanics is an important part of biophysics. *Bio* means life, and *mechanics i*s the study of the interaction of a physical object with its surroundings. Therefore, *biomechanics* is the study of a living object's interaction with its surroundings, which also includes the study of how living organisms move and the causes of this motion.

These sections explain a bit more about what biomechanics is. I discuss rules because biophysicists love rules, explain what happens when forces try to change an object's motion, and look at the motion of an object.

Surveying the rules

Biomechanics has many rules because things don't happen randomly or by chance. Things happen because of actions, and these rules tell you what the consequences of an action are. These rules are usually called *laws,* which can't be broken.

Some important laws in biomechanics are

- **Newton's first law of motion, the law of inertia:** This law tells you objects are lazy, and you have to force them to change their motion.
- **Newton's second law of motion, the law of acceleration:** If you force an object to change its motion, then this law tells you how the motion will change.
- **Newton's third law of motion, the law of action and reaction:** This law states that if one object applies a force to a second object, then the second object will apply the opposite force back on the first object.
- **(Law of) conservation of momentum:** This law tells you that the total momentum of an isolated system doesn't change even if the objects within the system are bouncing off each other.
- **(Law of) conservation of energy:** The law tells you that you can't create or destroy energy; you can only change it from one form to another.
- **The work-energy theorem:** If you want to change an object's kinetic energy, then you must do work on the object.

Chapter 4 introduces these rules of physics that are applicable to biomechanics. This chapter also explains what a force is and what energy is as well as the connection between forces and energy.

Focusing on statics

Statics, the situation when a biological system isn't moving, even if under the influence of forces, is another important part of biophysics. The physics of biological systems that aren't moving can be very complex. Chapter 5 lays out the procedure for solving problems in translational equilibrium, then problems in rotational equilibrium. Finally, it combines the two, which is called *static equilibrium.*

Meanwhile, Chapter 6 includes the following:

- Calculating the center of mass of a biological system
- Determining the effective weight of a biological organism
- Viewing biological organisms as machines and levers
- Examining different ways that biological organisms can be deformed
- Eyeing different properties of the organism when it's enlarged or shrunk.

Going the dynamic route

Biomechanics looks at the motion of biological organisms and the forces that act on them. Chapter 7 identifies what causes the forces that generate the motion. Two main types of motion are as follows:

- **Linear motion:** This type includes situations where the net force is one-dimensional such as in skydiving. You can study this type of motion by using forces or looking at the energy of the system.
- **Circular motion:** This type includes torques and rotational energy. It's useful in situations, such as in diving competitions or certain gymnastics events where the athlete is spinning and twisting.

Moving around with kinematics

Kinematics is the study of how biological organisms move without worrying about why. All you need to know is the acceleration, velocity, and position to describe an object's motion or a system of objects' motions. Chapter 7 is the "why" objects move, and Chapter 8 is the "how" objects move. Chapter 8 starts with describing the linear motion of objects and then switches to circular motion.

Eyeing the Physics of Fluids

Fluids are a collection of objects (usually molecules) that stick together as a group, but the objects move about randomly relative to each other, unlike solids where molecules will be fixed and not travel from one side to another side. Fluids play a key role in biophysics, such as blood transporting oxygen to the cells or the motion of sap in a plant.

These sections examine how fluids influence the world around them. I begin with the rules and forces in fluids, discuss the flow of different types of fluids, and finish with discussing how material enters and leaves our bodies.

Understanding fluid's mechanics and cohesive forces

Fluids obey rules and this section goes over some of the foundational rules. Some of these ideals are

- **Pascal's principle:** A (incompressible) fluid at rest will transmit a change in pressure to all points in the fluid equally. For example, fill a balloon up with water and then squeeze the top of the balloon. The water in the balloon will increase in pressure everywhere within the balloon.
- **Archimedes's principle:** Any object wholly or partially immersed in a fluid (or gas) has a force exerted on it by the fluid (or gas) called the *buoyant force,* which is equal to the weight of the fluid displaced by the object.
- **Conservation of mass:** The total mass of the fluid doesn't change unless you add or remove fluid from the system.
- **Bernoulli's equation:** The equation shows how the speed of the fluid will change from forces acting on the fluid. For example, if you pour a fluid out of your glass, it will pick up speed as it flows toward the floor.
- **Cohesive force:** It's the attractive force between molecules. This force keeps a water drop together and gives rise to surface tension. The force is called *adhesion* when it's between molecules that are different, say the fluid and the container.

Chapter 9 expands on these ideas and concepts related to fluids.

Tackling fluid dynamics

Fluid dynamics is the study of moving fluids. The properties of fluids are very important in many fields of biophysics. For example, you may be interested in how blood flows through restricted channels, how to throw a ball to maximize its curve, or how to optimize an irrigation system in environmental science.

REMEMBER

Viscosity is a measure of a fluids resistance to change. For example, maple syrup is more viscous than water. Fluids can be split into two main groups:

- **Nonviscous fluids:** The first case corresponds to situations where the viscosity can be ignored
- **Viscous fluids:** In these fluids, the viscosity plays an important role and can't be ignored.

In the case of viscous fluids, you need to consider what type of fluid you have and the type of flow:

- **Newtonian fluids:** In a *Newtonian fluid,* the ratio of the stress to the strain is a constant, which is the viscosity.
- **Non-Newtonian fluids:** If a fluid is not Newtonian, then it's non-Newtonian. Water is Newtonian, whereas ketchup is non-Newtonian.
- **Laminar flow:** A viscous fluid flowing at low speeds will form layers with different speeds and little mixing between the layers. The layer closest to a boundary will try to match the boundary's speed.
- **Turbulent flow:** A viscous fluid flowing in an unpredictable manner with rapidly changing properties. The smoke rising from a campfire is a turbulent flow (except the smoke closest to the flame, which is laminar flow).

Chapter 10 looks more closely at the dynamics of fluids.

Moving through membranes and porous materials

Porous materials allow fluids to flow through them, such as water flowing through sand. *Membranes* are boundaries within biological organisms that separate two fluids. Membranes are usually very thin and play different roles in a biological system. For example, the eardrum *(tympanic membrane)* has air on both sides and vibrates when sound waves hit it, whereas the membrane within the lungs is semi-permeable, allowing oxygen molecules to go from the air into the blood and carbon dioxide to move from the blood into the air. These materials play a very important role in biological organisms and are an important area of biophysics.

You have probably noticed that perfume lingers in the air for a long time after it has been sprayed into the air. It takes the perfume a long time to dissipate unless you turn on a fan. This concept, called *diffusion,* is important in understanding how materials within a fluid are transported and how the material moves through a membrane. Chapter 11 starts with diffusion. Chapter 11 then discusses more about membranes and porous materials, including human *metabolism,* the conversion of food into energy, and the elimination of molecules from the human body.

Comprehending Waves and Sound

Waves are a means by which energy is transferred from one region of space to another region. As the wave propagates through space, it's usually associated with the temporary disruption of the material in that region. (You can think of the crest of a water wave as it moves across the surface of the water.) *Sound* is a pressure wave that causes the molecules in the gas, liquid, or solid to temporarily vibrate. They're important to the study of biophysics because biological systems need energy to do work. Music and communication between animals are very important.

The following sections break it up a little more. These sections mention how the wave disrupts the material as the wave propagates through the material, explains how sound is made, followed by how the ear hears those sounds, and discusses some applications of sound waves.

Disturbing the material

A *wave* propagating through a material will usually cause the material to be disturbed from its rest position. After the wave has passed, then everything usually returns to normal. In some cases, the energy in the wave will cause irreparable damage to the material, and it can't return back to its original state. Think of a sonic boom shattering a window.

Related to this is *harmonic motion,* where the material bounces back and forth or up and down. Water waves at the beach cause the water to go up and down in a repeating pattern. In many situations, the harmonic motion obeys *Hooke's law,* which states that the farther the material is distorted from its rest position, the stronger the force to restore the material back to its normal position. Many applications of waves and harmonic motion exist in biophysics. For example, you can use harmonic motion (Hooke's law) to find the weight of a virus.

REMEMBER

The different types of waves include the following:

- **Longitudinal waves:** These types of waves have the material vibrate back and forth in the direction parallel to the wave's motion.
- **Transverse waves:** These types of waves have the material vibrate back and forth in a perpendicular direction to the wave's motion.
- **Electromagnetic radiation:** These are transverse waves, which are unique in that they do not need a medium to propagate through.
- **Sound waves:** These are longitudinal pressure waves.
- **Water waves:** Water waves can be of different types, but the ones that people are the most familiar with are the surface water waves that propagate toward the shore.

Chapter 12 takes a closer look at these types of waves and how waves interact with other waves of the same kind and how the waves interact with their surroundings.

Knowing how animals and instruments make sound waves

Sound is pressure waves that are created by the vibration of an object, such as the vocal folds in a human or the skin on a drum. The resonance of air within a cavity, such as a flute, can also create sound. A few properties of sounds include the following:

- Sound needs the vibration of matter for the sound to propagate. Unfortunately, science fiction movies show sound waves propagating through space, which is wrong.
- Sound waves are longitudinal pressure waves in gasses, but they can be longitudinal and transverse in a solid.
- Sound travels at approximately 1,130 feet per second (344 meters per second) in air near sea level. The speed of sound depends on many factors including the temperature and density of the air.
- The speed of sound is equal to the *wavelength* (the distance from one crest to the next) times the *frequency* (the number of crests that pass by per second).
- **Interference:** Sound waves interacting with other sound waves interact either *constructively* (with enhanced amplitude) or *destructively* (with decreased amplitude).
- **Resonance:** Sound waves trapped between boundaries interact with their echo. At specific frequencies they will have constructive interference, which is called *resonance.* For example, blowing across the opening of an empty bottle makes a loud noise.

Chapter 13 discusses these properties in greater depth and looks at similarities and differences between a guitar and the human voice, as well as other instruments such as the clarinet and flute.

Hearing sound waves

Hearing is a very complex phenomenon and an important subject in biophysics. In addition, comprehending how hearing works can give an understanding of how biological systems work and how information is sent to the brain and processed. When sound waves hit the human body, the majority of the sound bounces off the body and travels elsewhere. You wouldn't be able to hear the sound except for the fact you have ears.