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Physics II For Dummies®

Learn to:

- Grasp physics terminology
- Get a handle on quantum and nuclear physics
- Understand waves, forces, and fields
- Make sense of electric potential and energy

Steven Holzner, PhD

Author of Physics For Dummies

Physics II FOR DUMMIES®

by Steven Holzner, PhD

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Steven Holzner taught Physics at Cornell University for more than a decade, teaching thousands of students. He's the award-winning author of many books, including *Physics For Dummies, Quantum Physics For Dummies,* and *Differential Equations For Dummies,* plus *For Dummies* workbooks for all three titles. He did his undergraduate work at MIT and got his PhD from Cornell, and he has been on the faculty of both MIT and Cornell.

Dedication

To Nancy, of course.

Author's Acknowledgments

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Contents at a Glance

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Introduction

For many people, physics holds a lot of terror. And Physics II courses do introduce a lot of mind-blowing concepts, such as the ideas that mass and energy are aspects of the same thing, that light is just a mix of electric and magnetic fields, and that every electron zipping around an atom creates a miniature magnet. In Physics II, charges jump, light bends, and time stretches — and not just because your instructor lost the class halfway through the lecture. Throw some math into the mix, and physics seems to get the upper hand all too often. And that's a shame, because physics isn't your enemy — it's your ally.

The ideas may have come from Albert Einstein and other people who managed to get laws and constants and units of measurement named after them, but you don't have to be a genius to understand Physics II. After all, it's only partially rocket science — and those are ultra-cool, nearing-the-speed-of-light rockets.

Many breakthroughs in the field came from students, researchers, and others who were simply curious about their world, who did experiments that often didn't turn out as expected. In this book, I introduce you to some of their discoveries, break down the math that describes their results, and give you some insight into how things work — as physicists understand it.

About This Book

Physics II For Dummies is for the inquiring mind. It's meant to explain hundreds of phenomena that you can observe all around you. For example, how does polarized light really work? Was Einstein really right about time dilation at high speeds? Why do the electromagnets in electric motors generate magnetism? And if someone hands you a gram of radioactive material with a half-life of 22,000 years, should you panic?

To study physics is to study the world. *Your* world. That's the kind of perspective I take in this book. Here, I try to relate physics to your life, not the other way around. So in the upcoming chapters, you see how telescopes and microscopes work, and you find out what makes a properly cut diamond so brilliant. You discover how radio antennas pick up signals and how magnets make motors run. You see just how fast light and sound can travel, and you get an idea of what it really means for something to go radioactive.

When you understand the concepts, you see that the math in physics isn't just a parade of dreadful word problems; it's a way to tie real-world measurements to all that theory. Rest assured that I've kept the math in this book relatively simple — the equations don't require any knowledge beyond algebra and trigonometry.

Physics II For Dummies picks up where a Physics I course leaves off — after covering laws of motion, forces, energy, and thermodynamics. Physics I and Physics II classes have some overlap, so you do find info on electricity and magnetism in both this book and in *Physics For Dummies.* But in *Physics II For Dummies,* I cover these topics in more depth.

A great thing about this book is that *you* decide where to start and what to read. It's a reference you can jump into and out of at will. Just head to the table of contents or the index to find the information you want.

Conventions Used in This Book

Some books have a dozen stupefying conventions that you need to know before you can start reading. Not this book. All you need to know is the following:

- New terms are given in italics, like *this,* and are followed by a definition.
- Variables, like *m* for *mass,* are in italics. If you see a letter or abbreviation in a calculation and it isn't italicized, you're looking at a unit of measurement; for instance, 2.0 m is 2.0 meters.
- Vectors — those items that have both a magnitude and a direction — are given in bold, like this: ***B.***

And those are all the conventions you need to know!

What You're Not to Read

Besides the main text of the book, I've included some extra little elements that you may find enlightening or interesting: sidebars and paragraphs marked with Technical Stuff icons. The sidebars appear in shaded gray boxes, and they give you some nice little examples or tell stories that add a little color or show you how the main story of physics branches out. The Technical Stuff paragraphs give you a little more technical information on the matter at hand. You don't need this to solve problems; you may just be curious.

If you're in a rush, you can skip these elements without hurting my feelings. Without them, you still get the main story.

Foolish Assumptions

In this book, I assume the following:

- You're a student who's already familiar with a Physics I text like *Physics For Dummies*. You don't have to be an expert. As long as you have a reasonable knowledge of that material, you'll be fine here. You should understand ideas such as mass, velocity, force, and so on, even if you don't remember all the formulas.
- You're familiar with the metric system, or SI (the International System of Units). You can convert between units of measurement, and you understand how to use metric prefixes. I include a review of working with measurements in Chapter 2.
- You know basic algebra and trigonometry. I tell you what you need in Chapter 2, so no need to worry. This book doesn't require any calculus, and you can do all the calculations on a standard scientific calculator.

How This Book Is Organized

Like physics itself, this book is organized into different parts. Here are the parts and what they're all about.

Part I: Understanding Physics Fundamentals

Part I starts with an overview of Physics II, introducing the goals of physics and the main topics covered in a standard Physics II course. This part also brings you up to speed on the basics of Physics I — just what you need for this book. You can't build without a foundation, and you get the foundation you need here.

Part II: Doing Some Field Work: Electricity and Magnetism

Electricity and magnetism are a big part of Physics II. Over the years, physicists have done a great job of explaining these topics. In this part, you see both electricity and magnetism, including info on individual charges, AC (alternating current) circuits, permanent magnets, and magnetic fields — and perhaps most importantly, you see how electricity and magnetism connect to create electromagnetic waves (as in light).

Part III: Catching On to Waves: The Sound and Light Kinds

This part covers waves in general, as well as light and sound waves. Of the two, light is the biggest topic — you see how light waves interact and interfere with each other, as well as how they manage when going through single and double slits, bouncing off objects, passing through glass and water, and doing all kinds of other things. The study of optics includes real-world objects such as lenses, mirrors, cameras, polarized sunglasses, and more.

Part IV: Modern Physics

This part brings you into the modern day with the theory of special relativity, the particle-wave duality of matter, and radioactivity. Relativity is a famous one, of course, and you see a lot of Einstein in this part. You also see many other physicists who chipped in on the discussion of matter's travels as waves. You read all about radioactivity and atomic structure, too.

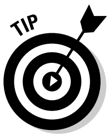
Part V: The Part of Tens

The chapters in this part cover ten topics in rapid succession. You take a look at ten physics experiments that changed the world, leading to discoveries in everything from special relativity to radioactivity. You also look at ten online calculators that can assist you in solving physics problems.

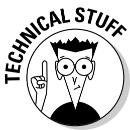
Icons Used in This Book

You find icons in this book, and here's what they mean:

This icon marks something to remember, such as a law of physics or a particularly important equation.



Tips offer ways to think of physics concepts that can help you better understand a topic. They may also give you tips and tricks for solving problems.



This icon means that what follows is technical, insider stuff. You don't have to read it if you don't want to, but if you want to become a physics pro (and who doesn't?), take a look.

Where to Go from Here

In this book, you can jump in anywhere you want. You can start with electricity or light waves or even relativity. But if you want the full story, start with Chapter 1. It's just around the corner from here. Happy reading!

If you don't feel comfortable with the level of physics taken for granted from Physics I, check out a Physics I text. I can recommend *Physics For Dummies* wholeheartedly.

Part I

Understanding Physics Fundamentals

The 5th Wave By Rich Tennant

"This is my old physics teacher, Mr. Wendt, his wife Doris, and their two children, Quark and Wormhole.".

In this part . . .

In this part, you make sure you're up to speed on the skills you need for Physics II. You start with an overview of the topics I cover in this book. You also review Physics I briefly, making sure you have a good foundation in the math, measurements, and main ideas of basic physics.

Chapter 1

Understanding Your World: Physics II, the Sequel

In This Chapter

- Looking at electricity and magnetism
- Studying sound and light waves
- Exploring relativity, radioactivity, and other modern physics

Physics is not really some esoteric study presided over by guardians who make you take exams for no apparent reason other than cruelty, although it may seem like it at times. Physics is the human study of *your* world. So don't think of physics as something just in books and the heads of professors, locking everybody else out.

Physics is just the result of a questioning mind facing nature. And that's something everyone can share. These questions — what is light? Why do magnets attract iron? Is the speed of light the fastest anything can go? — concern everybody equally. So don't let physics scare you. Step up and claim your ownership of the topic. If you don't understand something, demand that it be explained to you better — don't assume the fault is with you. This is the human study of the natural world, and you own a piece of that.

Physics II takes up where Physics I leaves off. This book is meant to cover — and unravel — the topics normally covered in a second-semester intro physics class. You get the goods on topics such as electricity and magnetism, light waves, relativity (the special kind), radioactivity, matter waves, and more. This chapter gives you a sneak preview.

Getting Acquainted with Electricity and Magnetism

Electricity and magnetism are intertwined. Electric charges in motion (not static, nonmoving charges) give rise to magnetism. Even in bar magnets, the tiny charges inside the atoms of the metal cause the magnetism. That's why you always see these two topics connected in Physics II discussions. In this section, I introduce electricity, magnetism, and AC circuits.

Looking at static charges and electric field

Electricity is a very big part of your world — and not just in lightning and light bulbs. The configuration of the electric charges in every atom is the foundation of chemistry. As I note in Chapter 14, the arrangement of electrons gives rise to the chemical properties of matter, giving you everything from metals that shine to plastics that bend. That electron setup even gives you the very color that materials reflect when you shine light on them.

Electricity studies usually start with electric charges, particularly the force between two charges. The fact that charges can attract or repel each other is central to the workings of electricity and to the structure of the atoms that make up the matter around you. In Chapter 3, you see how to predict the exact force involved and how that force varies with the distance separating the two charges.

Electric charges also fill the space around them with electric field — a fact familiar to you if you've ever felt the hairs on your arm stir when you've unloaded clothes from a dryer. Physicists measure electric field as the force per unit charge, and I show you how to calculate the electric field from arrangements of charges.

Next up is the idea of *electric potential,* which you know as *voltage.* Voltage is the work done per unit charge, taking that charge between two points. And yes, this is exactly the kind of voltage you see stamped on batteries.

With those three quantities — force, electric field, and voltage, you nail down static electric charges.

Moving on to magnetism

What happens when electric charges start to move? You get magnetism, that's what. *Magnetism* is an effect of electric charge that's related to but distinct from the electric field; it exists only when charges are in motion. Give an electron a push, send it sailing, and presto! You've got magnetic field. The idea that moving electric charges cause magnetic field was big news in physics — that fact's not obvious when you simply work with magnets.

Electric charges in motion form a *current,* and various arrangements of electric current create different magnetic fields. That is, the magnetic field you see from a single current-bearing wire is different from what you see from a loop of current — let alone a whole bunch of loops of current, an arrangement known as a *solenoid.* I show you how to predict magnetic field in Chapter 4.

Not only do moving electric charges give rise to magnetic fields, but magnetic fields also affect moving electric charges. When an electric charge moves through a magnetic field, that charge feels a force on it at right angles to the magnetic field and the direction of motion. The upshot is that left to themselves, moving charges in uniform magnetic fields travel in circles (an idea chemists appreciate, because that's what allows a mass spectrometer to sort out the chemical makeup of a sample). How big is the circle? How does the radius of the circle correlate with the speed of the charge? Or with the magnitude of the charge? Or with the strength of the magnetic field? Stay tuned. The answers to all these questions are coming up in Chapter 4.

AC circuits: Regenerating current with electric and magnetic fields

Students often meet electrical circuits in Physics I (you can read about simple direct current [DC] circuits in *Physics For Dummies*). In Chapter 5, you get the Physics II version: You take a look at what happens when the voltage and current in a circuit fluctuate in time in a periodic way, giving you *alternating voltage* and *currents*. You also encounter some new circuit elements, the inductor and capacitor, and see how they behave in AC circuits. Many of the electrical devices that people use every day depend on such elements in alternating currents.

In reading about the inductor, you also encounter one of the fundamental laws that relates electric and magnetic fields: Faraday's law, which explains how a changing magnetic field induces a voltage that generates its own magnetic field. This law doesn't just apply to inductors; it applies to all electric and magnetic fields, wherever they occur in the universe!

Riding the Waves

Waves are a huge topic in Physics II. A *wave* is a traveling disturbance that carries energy. If the disturbance is *periodic,* the amount of disturbance repeats in space and time over a distance called the *wavelength* and a time called the *period*. Chapter 6 delves into the workings of waves so you can see the relationships among the wave's speed, wavelength, and *frequency* (the rate at which cycles pass a particular point). In the rest of the chapters in Part III of this book, you explore particular types of waves, including electromagnetic waves (such as light and radio waves) and sound.

Getting along with sound waves

Sound is just a wave in air, and the various interactions of sound waves are just a result of the behaviors shared by all waves. For instance, sound waves can reflect off a surface — just let sound waves collide with walls and listen for the echo. Sound waves also interfere with other waves, and you can hear the effects — or silence, as the case may be. These two kinds of interaction form the basis for understanding the harmonic tones in music.

The qualities of a sound, such as pitch and loudness, depend on the properties of the wave. As you may have noticed by hearing the change of pitch of a siren on a police car as it passes by, pitch changes when the source or the listener moves. This is called the *Doppler effect*. You can take this to the extreme by examining the shock wave that happens when objects move very quickly through the air, breaking the sound barrier. This is the origin of the sonic boom. I cover all this and more in Chapter 7.

Figuring out what light is

You focus on light a good deal in Physics II. How light works is now well-known, but that wasn't always the case. Imagine the excitement James Clerk Maxwell must've felt when the speed of light suddenly jumped out of his equations and he realized that by combining electricity and magnetism, he'd come up with light waves. Before that, light waves were a mystery — what made them up? How could they carry energy?

After Maxwell, all that changed, because physicists now knew that light was made up of electrical and magnetic oscillations. In Chapter 8, you follow in Maxwell's footsteps to come up with his amazing result. There, you see how to calculate the speed of light using two entirely different constants having to do with how well electric and magnetic fields can penetrate empty space.

As a wave, light carries energy as it travels, and physicists know how to calculate just how much energy it can carry. That amount of energy is tied to the magnitude of the wave's electric and magnetic components. You get a handle on how much power that light of a certain intensity can carry in Chapter 8.

Of course, light is only the visible portion of the *electromagnetic spectrum* — and it's a small part at that. All kinds of electromagnetic radiation exist, classified by the frequency of the waves: X-rays, infrared light, ultraviolet light, radio waves, microwaves, even ultra-powerful gamma waves.

Reflection and refraction: Bouncing and bending light

Light's interaction with matter makes it interesting. For instance, when light interacts with materials, some light is absorbed and some reflected. This process gives rise to everything you see around you in the daily world.

Reflected light obeys certain rules. Primarily, the *angle of incidence* of a light ray — that is, the angle at which the light strikes the surface (measured from a line pointing straight out of that surface) — must equal the *angle of reflection* — the angle at which the light leaves the surface. Knowing how light is going to bounce off objects is essential to all kinds of devices, from the periscopes in submarines to telescopes, fiber optics, and even the reflectors that the Apollo astronauts placed on the moon. Chapter 10 covers the rules of reflection.

Light can also travel through materials, of course (or people wouldn't have windows, sunglasses, stained glass, and a lot more). When light enters one material from another, it bends, a process known as *refraction* — which is a big topic in Chapter 9. The amount the light bends depends on the materials involved, as measured by their *indexes of refraction*. That's useful to know in all kinds of situations. For example, when lens-makers understand how light bends when it enters and leaves a piece of glass, they can shape the glass to produce images. You take a look through lenses next.

Searching for images: Lenses and mirrors

If you're eager to look at the practical applications of Physics II topics, you'll probably enjoy optics. Here, you work with lenses and mirrors, allowing you to explore the workings of telescopes, cameras, and more.

Focusing on lenses

Lenses can focus light, or they can diverge it. In either case, you can get an image (sometimes upright, sometimes upside down, sometimes bigger than the object, sometimes smaller). The image is either virtual or real. In a *real image,* the light rays converge, so you can put a screen at the image location and see the image on the screen (like at the movies). A *virtual image* is an image from which the light appears to diverge, such as an image in a magnifying glass.

Armed with a little physics, you have the lens situation completely under control. If you're visually inclined, you can find info on the image using your drawing skills. I explain how to draw ray diagrams, which show how light passes through a lens, in Chapter 9.

You can also get numeric on light passing through lenses. The thin-lens equation gives you all you need to know here about the object and image, and you can even derive the magnification of lenses from that equation. So given a certain lens and an object a certain distance away, you can predict exactly where the image will appear and how big it will be (and whether it'll be upside down or not).

If one lens is good, why not try two? Or more? After all, that's the idea behind microscopes and telescopes. You get the goods on such optical instruments in Chapter 9, and if you want, you can be designing microscopes and telescopes in no time.

All about mirrors/srorrim tuoba llA

You can get numeric on the way mirrors reflect light, whether a mirror is flat or curved. For instance, if you know just how much a mirror curves and where an object is with reference to the mirror, you can predict just where the image of the object will appear.

In fact, you can do more than that — you can calculate whether the image will be upright or upside down. You can calculate just how high it will be compared to the original object. You can even calculate whether the image will be real (in front of the mirror) or virtual (behind the mirror). I discuss mirrors in Chapter 10.