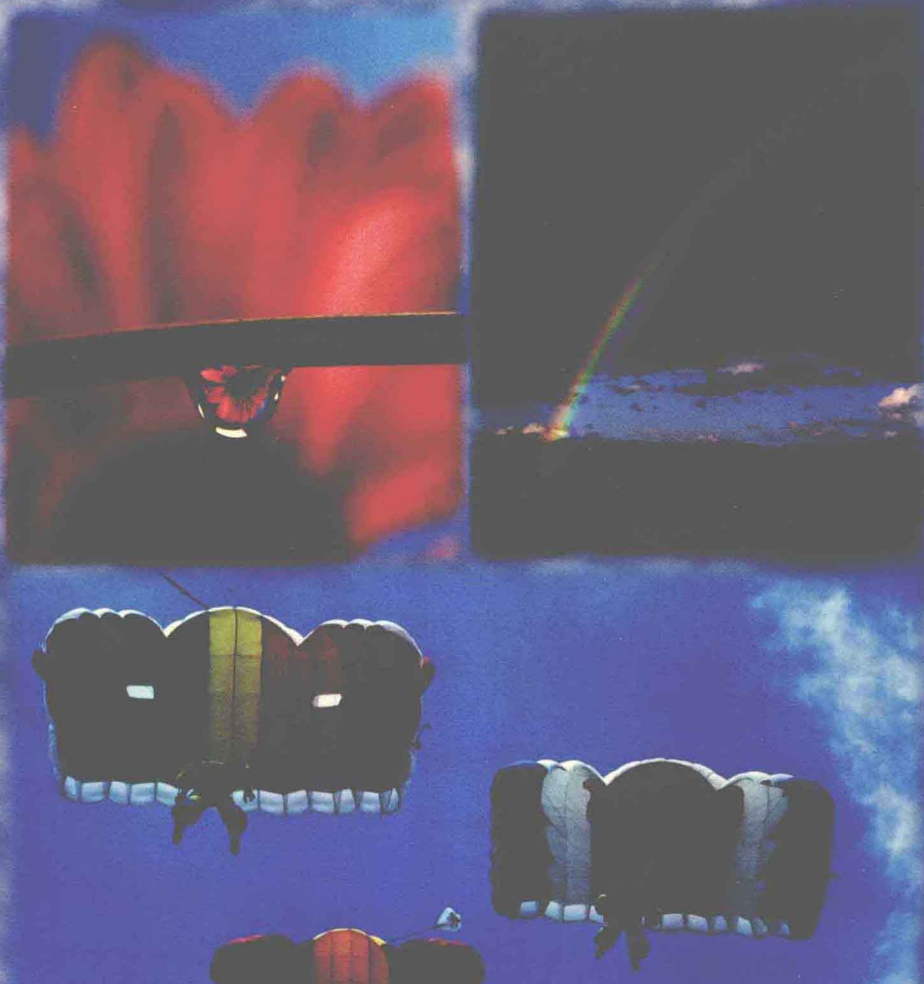
The Physics of Everyday Phenomena

A Conceptual Introduction to Physics



Third Edition

W. Thomas Griffith

The Physics of Everyday Phenomena

A Conceptual Introduction to Physics

Third Edition

W. Thomas Griffith

Pacific University

McGraw Hill

Boston Burr Ridge, IL Dubuque, IA Madison, WI New York San Francisco St. Louis
Bangkok Bogotá Caracas Lisbon London Madrid
Mexico City Milan New Delhi Seoul Singapore Sydney Taipei Toronto

McGraw-Hill Higher Education

A Division of The ***McGraw-Hill*** *Companies*

THE PHYSICS OF EVERYDAY PHENOMENA:
A CONCEPTUAL INTRODUCTION TO PHYSICS, THIRD EDITION

Published by McGraw-Hill, an imprint of The McGraw-Hill Companies, Inc., 1221 Avenue of the Americas, New York, NY 10020.

This book is printed on recycled, acid-free paper containing 10% postconsumer waste.

1 2 3 4 5 6 7 8 9 0 QPD/QPD 0 9 8 7 6 5 4 3 2 1 0

ISBN 0–07–232837–1

Vice president and editor-in-chief: *Kevin T. Kane*
Publisher: *JP Lenney*
Sponsoring editor: *Daryl Bruflodt*
Editorial assistant: *Jenni Lang*
Developmental editor: *Lori A. Sheil*
Marketing managers: *Mary K. Kittell/Debra A. Besler*
Project manager: *Sheila M. Frank*
Media technology project manager: *Phillip Meek*
Senior production supervisor: *Sandra Hahn*
Coordinator of freelance design: *Rick D. Noel*
Cover designer: *Sheilah Barrett*
Interior designer: *Kathleen Theis*
Photography: *SuperStock: ©Water Droplets on Flower Stem; Uniphoto Pictor: ©Rainbow; Skydiver*
Senior photo research coordinator: *Carrie K. Burger*
Photo research: *Shirley M. Lanners*
Supplement coordinator: *Tammy Juran*
Compositor: *Lachina Publishing Services*
Typeface: *10/12 Times Roman*
Printer: *Quebecor Printing Book Group/Dubuque, IA*

The credits section for this book begins on page 454 and is considered an extension of the copyright page.

Library of Congress Cataloging-in-Publication Data

Griffith, W. Thomas.
The physics of everyday phenomena : a conceptual introduction to physics / W. Thomas Griffith. — 3rd ed.
p. cm.
Includes index.
ISBN 0–07–232837–1
1. Physics. I. Title.

QC23 .G86 2001
530—dc21 00–029205
CIP

www.mhhe.com

Preface

The satisfaction of understanding how rainbows are formed, how ice skaters spin, or why ocean tides roll in and out—phenomena that we all have seen or experienced—is one of the best motivators available for building scientific literacy. This book attempts to make that sense of satisfaction accessible to nonscience majors. Intended for use in a one-semester or two-quarter course in conceptual physics, the book is written in a narrative style, frequently using questions designed to draw the reader into a dialogue about the ideas of physics. This inclusive style allows the book to be used by anyone interested in exploring the nature of physics and explanations of everyday physical phenomena.

Mathematics in a Conceptual Physics Course

The use of mathematics in a physics course is a formidable block for many students, particularly nonscience majors. Although there have been attempts to teach conceptual physics without any mathematics, these attempts miss an opportunity to help students gain confidence in using and manipulating simple quantitative relationships.

Clearly, mathematics is a powerful tool for expressing the quantitative relationships of physics. The use of mathematics can be carefully limited, however, and subordinated to the physical concepts being addressed. Many users of the first edition of this text felt that mathematical expressions appeared too frequently for the comfort of some students. In response, we substantially reduced the use of mathematics in the body of the text in the second edition. Most users have indicated that the current level is about right, so we have not changed the mathematics level in the third edition.

The logical coherence that was a strong feature of both earlier editions has been retained. Formulas are introduced carefully after conceptual arguments are provided, and statements in words of these relationships generally accompany their introduction. We have retained the boxed sample exercises that provide numerical illustrations of the ideas. No mathematics prerequisite beyond high school algebra should be necessary. A discussion of the basic ideas of very simple algebra is found in appendix A, together with some practice exercises for students who may need help with these ideas.

Other Features of This Edition

- **Everyday Phenomena Boxes.** We have continued to fine-tune a feature of this book that elicited many favorable comments for the earlier editions. Each chapter begins with an illustration from everyday experience and then proceeds to use it as a theme for introducing relevant physical concepts. Physics can seem abstract to many students, but using everyday phenomena and concrete examples reduces that abstractness. Each chapter also includes an *everyday phenomenon box*. These boxes analyze common phenomena in more detail and include examples from sports, automobile collisions, the operation of a flat-plate solar collector or a television set, and natural phenomena such as the tides, lightning, and rainbows.

■ **Conceptual Questions.** We have modified and slightly expanded the list of carefully worded *conceptual questions*, found at the end of each chapter. These questions, considered a strong feature of earlier editions, call for a short objective response regarding the direction, relative size, or existence of some effect, and are followed by a brief written explanation of that response. If these questions are made an integral part of the course, they can help students understand the key concepts more clearly than is the case with the more open-ended questions often found in other books.

■ **Numerical Exercises and Challenge Problems.** In the third edition, we have modified and expanded the simple *numerical exercises* and the somewhat more involved *challenge problems* found at the end of each chapter. The numerical exercises are useful in helping students get a feeling for the quantities involved and for performing simple computations involving physical concepts. The challenge problems are designed to provide those students who are comfortable with quantitative ideas an opportunity to explore these ideas in more depth.

■ **Home Experiments and Observations.** Since many courses for nonscience majors do not have a laboratory component, we have continued to develop the *home experiments and observations* found at the end of each chapter. The spirit of these home experiments is to enable students to explore the behavior of physical phenomena using easily available items, such as rulers, string, paper clips, balls, toy cars, and flashlight batteries. Many instructors have found these experiments useful for putting students into the exploratory and observational frame of mind that is important to scientific thinking. This is certainly one of our objectives in developing scientific literacy.

■ **Chapter Outlines, Questions, and Summaries.** The chapter outlines, questions, and summaries provide a clear framework for the ideas discussed in each chapter. One of the difficulties that students have in learning physics (or any subject) is that they fail to construct the big picture of how things fit together. A consistent chapter framework can be a powerful tool in helping students see how ideas mesh. Italicized *summary paragraphs* are found at the end of each section to supplement the more general summary at the end of the chapter. The subsection headings are often cast in the form of questions to motivate the reader and pique curiosity. A few key concepts form the basis for understanding physics, and these textual features reinforce this structure so that the reader will not be lost in a flurry of definitions and formulas.

How This Book Is Organized

We have retained the same organization of topics in the third edition as in the second edition. It is traditional with some minor variations. The chapter on energy (chapter 6) appears prior to that on momentum (chapter 7) so that energy ideas can be used in discussions of collisions. We placed wave motion in chapter 15, following electricity and magnetism and prior to chapter 16 on optics, rather than including it in the mechanics section. The chapter on fluids (chapter 9) follows mechanics and leads into the chapters on thermodynamics. The first 16 chapters are designed to introduce students to the major ideas of classical physics and can be covered in a one-semester course with some judicious paring.

The complete 20 chapters could easily support a two-quarter course, and even a two-semester course in which the ideas are treated thoroughly and carefully. Chapters 17 and 18, on atomic and nuclear phenomena, would be considered essential by many instructors, even in a one-semester course. If included in such a course, we recommend curtailing coverage in other areas to avoid student overload.

Some instructors would prefer to put chapter 19 on relativity at the end of the mechanics section or just prior to the modern physics material. Relativity has little to do with everyday phenomena, of course, but is included because of the high interest that it generally holds for students. The final chapter (20) introduces a variety of topics in modern physics—including particle physics, cosmology, semiconductors, computers, and superconductivity—that could be used to stimulate interest at various points in a course.

One plea to instructors, as well as to students using this book: Don't try to cram too much material into too short a time! We have worked diligently to keep this book to a reasonable length while still covering the core concepts usually found in an introduction to physics. These ideas are most enjoyable when enough time is spent in lively discussion and in consideration of questions so that a real understanding develops. Trying to cover material too quickly defeats conceptual learning and leaves students in a dense haze of words and definitions. Less can be more if a good understanding results.

ACKNOWLEDGMENTS

A large number of people have contributed to this third edition, either directly or indirectly. I extend particular thanks to those who participated in reviews of the manuscript. Their thoughtful suggestions have had direct impact upon the clarity and accuracy of this edition, even when it was not possible to fully incorporate all of their ideas due to space limitations or other constraints. The reviewers include:

Murty A. Akundi
Xavier University of Louisiana

Charles Ardary
Edmonds Community College

James W. Arrison
Villanova University

Richard A. Atneosen
Western Washington University

Dr. Jean-Claude Ba
Columbus State Community College

Maria Bautista
University of Hawaii

Richard L. Bobst
LaSierra University

Ferdinando Borsa
Iowa State University

Richard A. Cannon
Southeast Missouri State University

Edward H. Carlson
Michigan State University

Cary Caruso
Fayetteville State University

Rory Coker
University of Texas, Austin

Doug Davis
Eastern Illinois University

Renee D. Diehl
Penn State University

David Donnelly
Sam Houston State University

Abbas M. Faridi
Orange Coast College

Clarence W. Fette
Penn State University

Lyle Ford
University of Wisconsin, Eau Claire

Bernard Gilpin
Golden West College

Kenneth D. Hahn
Truman State University

John M. Hauptman
Iowa State University

H. James Harmon
Oklahoma State University

Lionel D. Hewett
Texas A & M University, Kingsville

Robert C. Hudson
Roanoke College

Stanley T. Jones
University of Alabama

Sanford Kern
Colorado State University

James Kernohan
Milton Academy

John B. Laird
Bowling Green State University

Paul L. Lee
California State University, Northridge

Joel M. Levine
Orange Coast College

John Lowenstein
New York University

Robert R. Marchini
University of Memphis

Paul Middents
Olympic College

Joseph Mottillo
Henry Ford Community College

William J. Mullin
University of Massachusetts, Amherst

Dr. Arnold Pagnamenta
University of Illinois at Chicago

Russell L. Palma
Sam Houston State University

Ervin Poduska
Kirkwood Community College

Joseph A. Schaefer
Loras College

Rahim Setoodeh
Milwaukee Area Technical College

Elwood Shapanasky
Santa Barbara City College

Lawrence C. Shepley
University of Texas, Austin

Bradley M. Sherrill
Michigan State University

Cecil G. Shugart
University of Memphis

John W. Snyder
Southern Connecticut State University

Thor F. Stromberg
New Mexico State University

Charles R. Taylor
Western Oregon State College

Fred Thomas
Sinclair Community College

Jeffrey S. Thompson
University of Nevada, Reno

Paul Varlashkin
East Carolina University

Douglas Wendel
Snow College

John Yelton
University of Florida

Mike Young
Santa Barbara City College

I also wish to acknowledge the contributions of the editorial staff and book team members at McGraw-Hill Higher Education, whose commitment of time and enthusiasm for this work have helped enormously in pushing this project forward.

In addition, I owe a huge debt of thanks to my colleagues at Pacific University for helpful suggestions as well as for their forbearance when this project limited my time for other activities. All of my colleagues have given their enthusiastic support to the project.

Finally, I owe a debt of gratitude to my family, who has suffered without complaint the time that this project has stolen from other activities. My wife Adelia and my boys Lewis, Clark, and Mark have also willingly served as guinea pigs as I have tested demonstrations or ideas. Their support has been constant and essential to this work.

The **Physics** of Everyday Phenomena

A Conceptual Introduction to Physics

Contents

7 Momentum and Impulse *115*

8 Rotational Motion of Solid Objects *134*

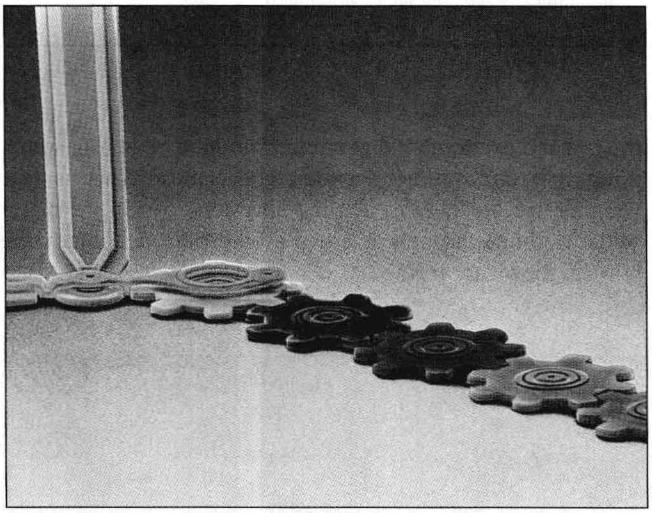
UNIT 2 Fluids and Heat

9 The Behavior of Fluids *158*

10 Temperature and Heat *179*

UNIT 4 Wave Motion and Optics

UNIT 5 The Atom and Its Nucleus



CHAPTER

1

Physics, the Fundamental Science

Chapter Overview

The main objective of this chapter is to help you understand what physics is and where it fits in the broader scheme of the sciences. A secondary purpose is to acquaint you with some of the features of this book and give some tips on how to use them most effectively.

Chapter Outline

1. **The scientific enterprise.** What is the scientific method? How do scientific explanations differ from other types of explanation?
2. **The scope of physics.** What is physics. How is it related to the other sciences and to technology? What are the major subfields of physics?
3. **The role of measurement and mathematics.** Why are measurements so important? Why is mathematics so extensively used in science? Can physics be done without mathematics?
4. **Physics and everyday phenomena.** How is physics related to everyday experience and common sense? What are the advantages of using physics to understand common experience?
5. **How to use the features of this book.** What are the features of this book? How can they help you to get a good grounding in physics and make the most of the course?

Imagine that you are riding your bike on a country road on an Indian-summer afternoon. The sun has come out after a brief shower, and as the rain clouds move on, a rainbow appears in the east (fig. 1.1). A leaf flutters to the ground, and an acorn, shaken loose by a squirrel, misses your head by only a few inches. The sun is warm on your back, and you are at peace with the world around you.

No knowledge of physics is needed to savor the moment, but your curiosity may bring some questions to mind. Why does the rainbow appear in the east rather than in the west, where it may also be raining? What causes the colors to appear? Why does the acorn fall more rapidly than the leaf? Why is it easier to keep your bicycle upright while you are moving than when you are standing still?

Your curiosity about questions like these is similar to what motivates scientists. Learning to devise and apply theories or models that can be used to understand, explain, and predict such phenomena can be a rewarding intellectual game. Crafting an explanation and testing it with simple experiments or observations is fun. That enjoyment is often missed when the focus of a science course is on accumulating facts.

This book can enhance your ability to enjoy the phenomena that are part of everyday experience. Learning to produce your own explanations and to perform simple experimental tests can be gratifying. The questions posed here lie in the realm of physics, but the spirit of inquiry and explanation is found throughout science and in many other areas of human activity. The greatest rewards of scientific study are the fun and excitement that come from understanding something that has not been understood before. This is true whether we are talking about a physicist making a major scientific breakthrough or about a bike rider understanding how rainbows are formed.

Figure 1.1 A rainbow appears to the east in the Columbia River Gorge on a summer afternoon. How can this phenomenon be explained? (See p. 322.)

STUDY HINT

If you have a clear idea of what you want to accomplish before you begin to read a chapter, your reading will be more effective. The questions in the chapter outline—as well as those in the subheadings of each section—can serve as a checklist for measuring your progress as you read. A clear picture of what questions are going to be addressed and where the answers will be found forms a mental road map to guide you through the chapter. Take a few minutes to study the outline and fix this road map in your mind. It will be time well spent.

1.1 THE SCIENTIFIC ENTERPRISE

How do scientists go about explaining something like the rainbow described in the introduction to this chapter? How do scientific explanations differ from other types of explanations? Can we count on the scientific method to explain almost anything? It is important to understand what science can and cannot do.

Philosophers have devoted countless hours and pages to questions about the nature of knowledge, and of scientific knowledge in particular. Many issues are still being refined and debated. Science has grown rapidly during the twentieth century and has a tremendous impact on our lives. What is it about science that explains its impressive advances and steady expansion?

How are scientific explanations developed?

Let's consider a specific example of how a scientific explanation comes to be. Where would you turn for an explanation of how rainbows are formed? If you returned from your bike ride with that question on your mind, you might turn to an encyclopedia or a textbook on physics, look up *rainbow* in the index, and read the explanation found there. Are you behaving like a scientist?

The answer is both yes and no. Many scientists would do the same if they were unfamiliar with the explanation. When we do this, we appeal to the authority of the textbook author and to those who preceded the author in inventing the explanation. Appeal to authority is one way of gaining knowledge, but you are at the mercy of your source for the validity of your explanation. You are also hoping that someone has already raised the same question and done the work to create and test an explanation.

Suppose you go back three hundred years or more and try the same approach. One book might tell you that a rainbow is a painting of the angels. Another might speculate on the nature of light and its interactions with raindrops but be quite tentative in its conclusions. All of these books might have seemed authoritative in their day. Where, then, do you turn? Which explanation will you accept?

If you are behaving like a scientist, you might begin by reading the ideas of other scientists about light and then test these ideas against your own observations of rainbows. You would carefully note the conditions when rainbows appear, the position of the sun relative to you and the rainbow, and the position of the rain shower. What is the order of the colors in the rainbow? Have you observed that order in other phenomena?

You would then invent an explanation or **hypothesis** using current ideas on light and your own guess about what happens as light passes through a raindrop. You could devise experiments with water drops or glass beads to test your hypothesis. (See chapter 16 for a modern view of how rainbows are formed.)

If your explanation is consistent with your observations and experiments, you could report it by giving a paper or talk to scientific colleagues. They may criticize your explanation, suggest modifications, and perform their own experiments to confirm or refute your claims. If others confirm your results, your explanation will gain support and eventually become part of a broader **theory** about phenomena involving light. The experiments that you and others do may also lead to the discovery of new phenomena, which will call for refined explanations and theories.

What is critical to the process just described? First is the importance of careful observation. Another aspect is the idea of testability. An acceptable scientific explanation should suggest some means to test its predictions by observations or experiment. Saying that rainbows are the paintings of angels may be poetic, but it certainly is not testable by mere humans. It is not a scientific explanation.

Another important part of the process is a social one, the communication of your theory and experiments to colleagues (fig. 1.2). Submitting your ideas to the criticism (at times blunt) of your peers is crucial to the advance of science. Communication is also important in assuring your own care in performing the experiments and interpreting the results. A scathing attack by someone who has found an important error or omission in your work is a strong incentive for being more careful in the future. One person working alone cannot hope to think of all of the possible ramifications, alternative explanations, or potential mistakes in an argument or theory. The explosive growth of science has depended heavily on cooperation and communication.

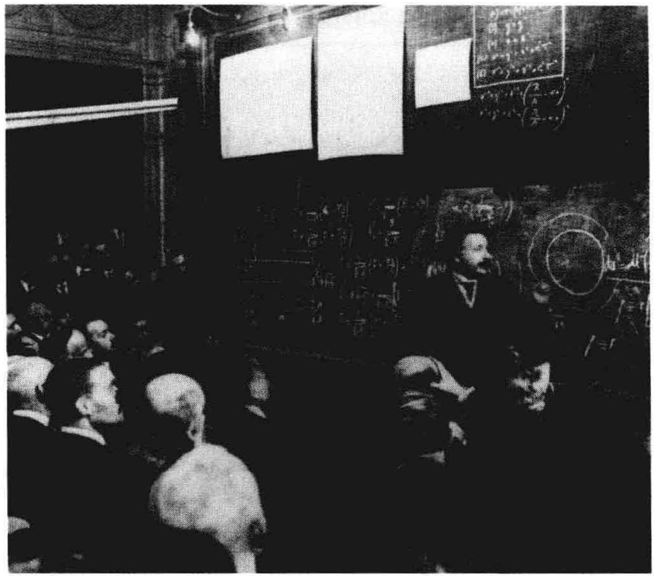


Figure 1.2 A scientific meeting. Communication and debate are important to the development of scientific explanations. The speaker is Albert Einstein.

What is the scientific method?

Is there something we could call **scientific method** within this description, and if so, what is it? The process just described is a sketch of how the scientific method works. Although there are variations on the theme, this method is often described as shown in table 1.1.

The steps in table 1.1 are all involved in our description of how to develop an explanation of rainbows. Careful observation may lead to **empirical laws** for when and where rainbows appear. An empirical law is a generalization derived from experiments or observations. An example of an empirical law is the statement that we see rainbows with the sun at our backs as we look at the rainbow. This is an important clue for developing our hypothesis, which must be consistent with this rule. The hypothesis, in turn, suggests ways of producing rainbows artificially that could lead to experimental tests and, eventually, to a broader theory.

This description of the scientific method is not bad, although it ignores the critical process of communication. Few scientists are engaged in the full cycle that these steps suggest. Theoretical physicists, for example, may spend all of their time with step 3. Although they have some interest in experimental results, they may never do any experimental work themselves. Today, little science is done simply by observing, as implied by step 1. Most experiments and observations take place to test a hypothesis or existing theory. Although the scientific method is presented here as a stepwise