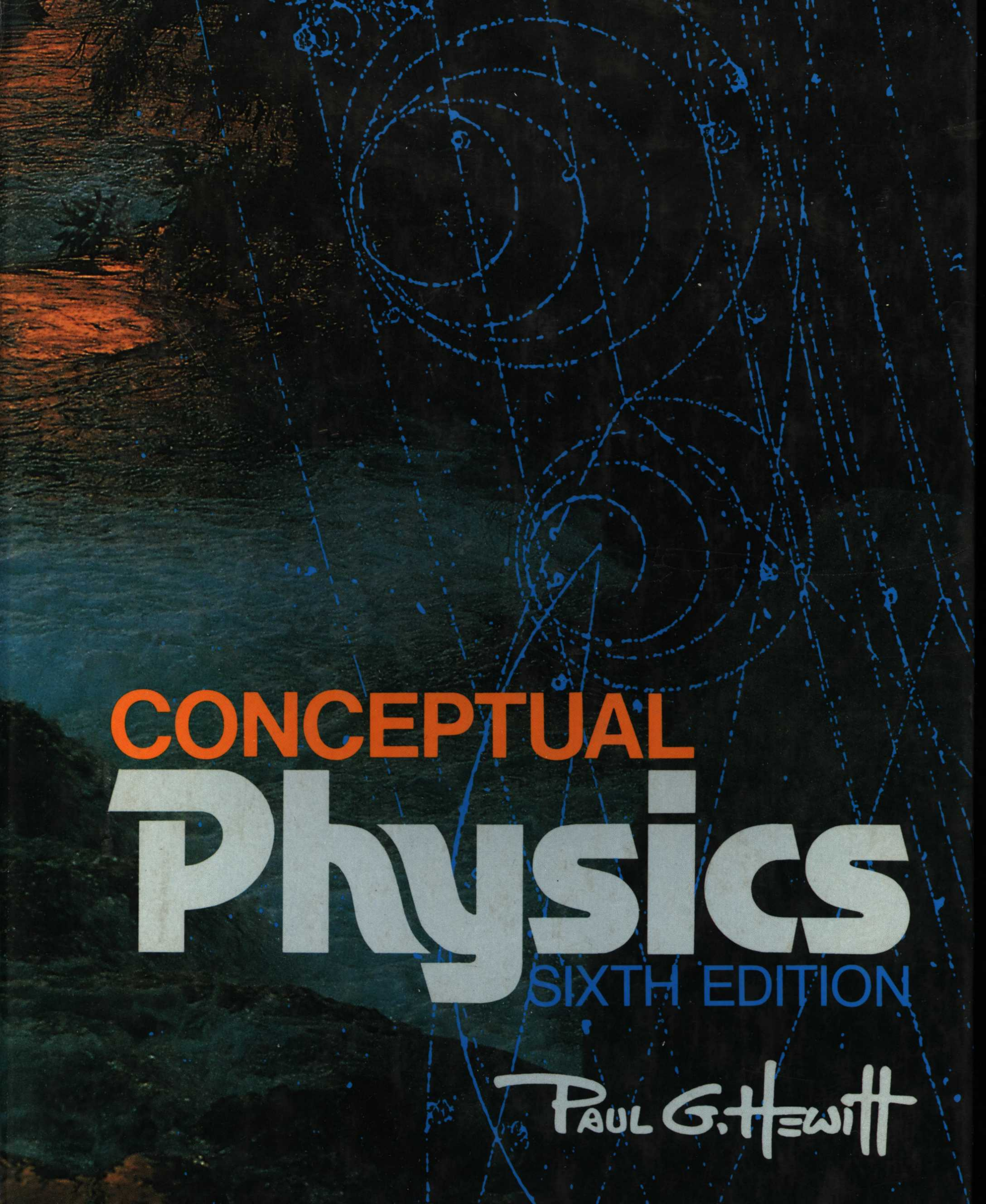


CONCEPTUAL Physics

SIXTH EDITION

Paul G. Hewitt

CONCEPTUAL Physics

SIXTH EDITION

Written & Illustrated by

Paul G. Hewitt

City College of San Francisco

HarperCollinsPublishers

Produced by The Compage Company

Cover design: Paul G. Hewitt
Cover photo: Don Briggs
Cover logo design and title page design: Ernie Brown
Interior design and page makeup: Christy Butterfield and Elizabeth Victor
Editorial production: Pearl C. Vapnek
Photo research: Lindsay Kefauver and Caroline Pincus
Copyediting: Judith Hibbard
Indexing: Steven M. Sorensen
Composition: GTS

Library of Congress Cataloging-in-Publication Data

Hewitt Paul G.
Conceptual physics.

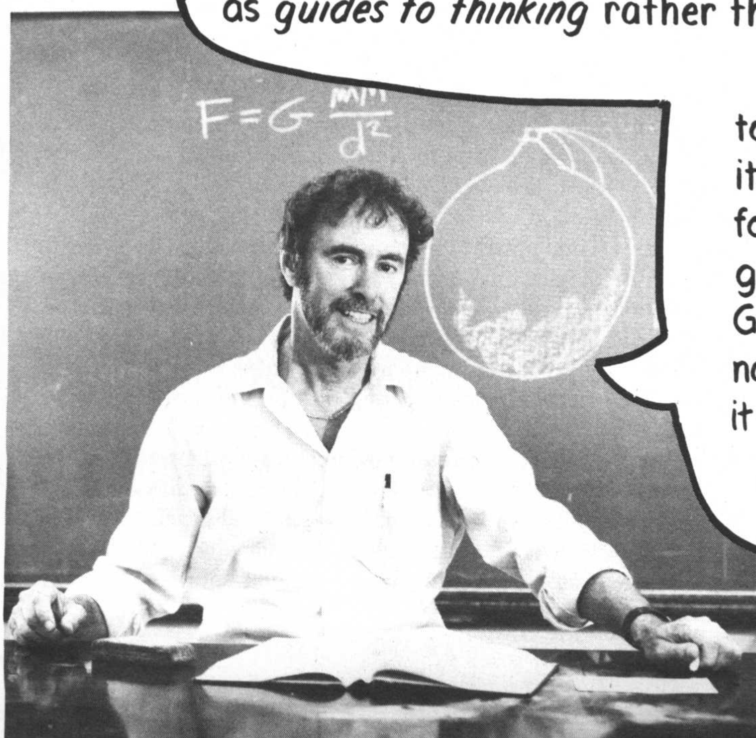
Bibliography: p.
Includes index.
1. Physics. I. Title
QC23.H56 1989 530 88-29704
ISBN 0-673-39847-1

8 9 10 -RRC- 94 93 92

Printed in the United States of America

To the Student

You know you can't enjoy a game unless you know its rules—whether it's a ball game, a computer game, or simply a party game. Likewise, you can't fully appreciate your surroundings until you understand the rules of nature. Physics is about the rules of nature—so beautifully elegant that it can be neatly described mathematically. That's why many physics courses are treated as applied mathematics. But introductory physics that emphasizes computation misses something essential—*comprehension*—a gut feeling for the concepts. This book emphasizes comprehension rather than computation. We treat physics *conceptually*—in down-to-earth *English* rather than in mathematical language. You'll see the mathematical structure of physics in frequent equations, but you'll see the equations as *guides to thinking* rather than as recipes for computation.



I enjoy physics, and you will too—because you'll understand it. If you get hooked and take a follow-up course, *then* you can get into mathematical problems. Go for comprehension of concepts now, and if computation follows, it will be with understanding.

Enjoy your physics!

PAUL G. HEWITT

To the Instructor

Because physics is the basic science—the foundation of chemistry, biology, and all disciplines of science—it should be part of the educational mainstream for both science and nonscience students. Unfortunately, its mathematical language deters the average nonscience student. But when the ideas of physics are presented conceptually and when equations are seen to be guides to thinking rather than recipes for algebraic manipulation, our discipline is accessible to all students. And for students who will continue in the study of physics, I am convinced that the ideas of physics should be first understood conceptually before being used as a base for applied mathematics.

This book seeks to build that conceptual base. For the nonscience student, it is a base from which to view nature more perceptively—to see that surprisingly few relationships make up its rules. For the science student, it is this as well as being a springboard to a greater involvement in physics. A first-semester overview of Newtonian and modern physics for science majors will help to correct a missing essential in physics education: the practice of conceptualizing before calculating. For nonscience and science students alike, a conceptual way of looking at physics shapes analytical thinking.

New to This Edition

Although the sequence from classical mechanics to modern physics and the overall organization of this edition are much the same as in previous editions, this edition has been almost completely rewritten. The chapter on astrophysics has been omitted to make room for three new chapters, on nonlinear motion, satellite motion, and the properties of light. Part I begins with linear motion in Chapter 2 and is followed with nonlinear motion in the new Chapter 3. In this new chapter, projectile motion extends to satellite motion, but unlike the previous edition, a thorough treatment of satellite motion is deferred to its own Chapter 9, which follows the chapter on gravity. Since spacefaring activities are of general interest and already capture the imagination of our students, the brief introduction of satellite motion in Chapter 3 can build an early interest in physics. Vectors, which were relegated to an appendix in previous editions, are introduced in Chapter 3. Only simple cases of velocity vectors are treated in this early chapter, and a more general treatment is in Appendix III. As with the fifth edition, the chapter on momentum logically follows the chapter on Newton's laws, so there is no gap between Newton's third law and momentum conservation. Appendix IV of the fifth edition, "The Universal Gravitational Constant, *G*," is now incorporated in Chapter 8, on gravity. There are no major changes in the order of topics in Parts 2, 3, and 4. In Part 5 minor reordering of topics occurs in the chapters on magnetism and electromagnetic induction. Part 6 now begins with a new chapter on the properties of light. The chapter on color now precedes the chapter on reflection and refraction. Part 6 ends with an introduction to quantum physics, which carries into the first chapter in Part 7. Part 8 is confined to special and general relativity, with no chapter on astrophysics. I feel that this edition is a smoother and more readable treatment than the previous edition, with many new insights sprinkled throughout that I hope your students will enjoy.

Pedagogy

An important change concerns the review questions at the end of each chapter. All important ideas are framed in relatively easy-to-answer review questions and are cited by chapter sections. They are, as the name implies, a review of chapter material. Their purpose is simply to provide a structured way to review the chapter. They are not meant to challenge the student's intellect, for in the vast majority of cases, the answers can be simply looked up. The exercises, on the other hand, play a different role. These have been streamlined, with new ones added. Some are moderately simple and are designed to prompt the application of physics to everyday situations, while others are more sophisticated and call for considerable critical thinking. Some are quantitative and involve simple, straightforward calculations that will help your students capture the idea being treated without requiring algebraic skills. The challenge to your students will be in the conceptual reasoning and critical thinking that are called for in the exercises.

As in previous editions, units of measurement are not emphasized. When used, they are almost exclusively expressed in SI (exceptions include such units as calories, grams per centimeter cubed, and light years). Mathematical derivations are avoided in the main body of the text and appear in footnotes or in the appendixes.

Ancillary Materials

More than enough material is included for a one-semester course, which allows for a variety of course designs to fit your taste. These are suggested in the *Instructor's Manual*, which you'll find to be different from most instructor's manuals. It contains many lecture ideas and topics not treated in the textbook, as well as teaching tips and suggested step-by-step lectures and demonstrations.

Be sure to get the ancillary packet, which includes, among other important items, transparency masters titled "Next-Time Questions." These are like the "Figuring Physics" cartooned questions and answers that appear each month in *The Physics Teacher.* New to this edition are "Conceptual Physics Illustrations," which can help make your chalkboard presentations more interesting. The "Test Bank" booklet has been expanded and is also available on upgraded computer disks not only for Apple II and IBM PCs, but for the Macintosh as well.

Last but not least, there is finally a lab manual for *Conceptual Physics*, written by Paul Robinson. In addition to interesting laboratory experiments, it includes a range of activities similar to the home projects in *Conceptual Physics*. These guide students to experience phenomena before they quantify the same phenomena in a follow-up laboratory experiment.

Go to it! Your conceptual physics course really can be the most interesting, informative, and worthwhile science course available to your students.

Acknowledgments

For contributions to every chapter in this edition, I especially wish to thank Charlie Spiegel, research assistant, California State University, Domingues Hills, whose great help with this book is just a small part of his effort to bring mathematics, science, and language closer together. I am also indebted to former student Ronald E. Lindemann, whose many valuable ideas are sprinkled all throughout this book. For researching information on thermodynamics I thank student Clifford M. Braun (left foreground, Figure 7-39), San Francisco State University. I am grateful for the help of my friend Paul Robinson, Computech, Fresno, California. For supplying 3-D figures and helpful information, I thank my friend Marshall Ellenstein, Maine West High School, Chicago. I am especially grateful to Charlie Hibbard, Galileo High School, San Francisco, for critiquing the entire book with emphasis on improving the chapter-end review questions and exercises. I am grateful to my colleagues at City College of San Francisco (CCSF) for their suggestions and assistance: Jim Conley, Jim Court, Frank Creese, Jerry Hosken, Jim Kurck, Will Maynez (center, Figure 5-14), Dave Wall, and Norman Whitlatch. Others who have contributed to this edition include Eric Bergmark, Sellwood Middle School, Oregon; Gabe Espinda and Ron Hipschman, the Exploratorium, San Francisco; Tenny Lim (Figure 6-4), Jet Propulsion Laboratory, California; architect Wade Porter, Wyoming; Joseph Scherrer, Germantown Academy, Pennsylvania; John J. Spokas, Illinois Benedictine College; Jearl Walker, Cleveland State University; Dick Walton, Rocky Mountain College, Montana; and Dean Zollman, Kansas State University. I am most grateful to the many students, both at CCSF and at the world's most wonderful place to teach physics, the Exploratorium, for their valuable feedback.

For reviewing the entire manuscript, I thank Dack Lee, CCSF; John Hubisz, College of the Mainland, Texas; and Charlie Spiegel. For reviewing various chapters, I am indebted to Paul Doherty, the Exploratorium; Henry A. Garon, Loyola University; Chelcie Liu, CCSF; Keith Stowe, California Polytechnic State University, San Luis Obispo; and my sister Marjorie Hewitt Suchocki, Wesley Theological Seminary.

I am grateful to those whose own books initially served as principal influences and references: Theodore Ashford, *From Atoms to Stars*; Albert Baez, *The New College Physics—A Spiral Approach*; John N. Cooper and Alpheus W. Smith, *Elements of Physics*; Richard P. Feynman, *The Feynman Lectures on Physics*; Kenneth Ford, *Basic Physics*; Eric Rogers, *Physics for the Inquiring Mind*; Alexander Taffel, *Physics: Its Methods and Meanings*; UNESCO, *700 Science Experiments for Everyone*; and Harvey E. White, *Descriptive College Physics*.

Since this is the first edition written on a computer, the initial step of copying the previous edition into a computer was spread among several CCSF students; thanks to Alma Brady (second from right, Figure 5-14), Maria Burchard, Ann Chang (Figure 23-5), Winnie Fong (second from left, Figure 5-14), Angela Hirano, Chong Ho, and Pauline Ng (far right, Figure 5-14). For proofreading galleys, I thank my former students, Michael W. Moore and Ronald E. Lindemann; and for proofreading pages, Tom Hassett.

Special thanks to my friend and CCSF colleague Annette Rappleyea for helping with the test-bank questions and for writing and upgrading the computer program for the test bank. I thank my photographer-type friend Dave Vasquez (Figure 6-16) for his many photos, which add a nice touch to this edition. For supplying the cover photo of Havasu Creek in Grand Canyon, I thank Don Briggs. Thanks go to my lifelong friend Ernie Brown for designing the physics logo. I also thank my nephew and roommate Robert Baruffaldi (far left, Figure 5-14; far right, Figure 7-39) for his assistance not only in researching material, but in keeping my work and living environment orderly during the many months of writing and illustrating. For shading many of the illustrations, I am grateful to my daughter Leslie (Figure 10-1). I thank most of all Helen Yan (Figures 6-16, 13-8, and 15-11), physics graduate, University of California, Berkeley, for her graphics help and hand lettering—creating a more readable upper- and lowercase style that adorns the entire book and also the monthly column "Figuring Physics" in *The Physics Teacher*, the magazine of the American Association of Physics Teachers.

A special note of appreciation is due editor Ron Pullins, of Scott, Foresman/Little, Brown, for his very professional concern and assistance. Special thanks to Christy Butterfield for designing the book, and to Ken Burke, Pearl C. Vapnek, and Judith Hibbard, of The Compage Company, who produced the book.

San Francisco *Paul G. Hewitt*

Contents in Brief

Contents in Detail

PART 4 SOUND 321

PART 5 ELECTRICITY AND MAGNETISM 369

PART 8 RELATIVITY 635