# PHYSICS
## A World View

*third edition*

Kirkpatrick & Wheeler

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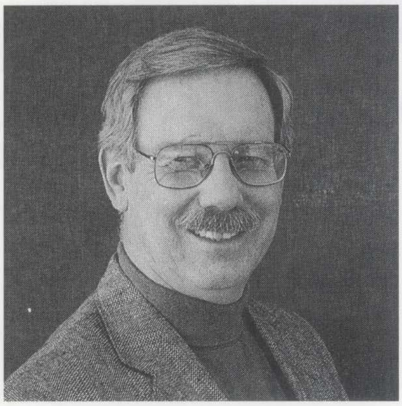

**Larry D. Kirkpatrick** *is professor of physics at Montana State University and adjunct curator of astronomy at the Museum of the Rockies. He served eight years as academic director and coach of the U.S. Physics Team that competes in the International Physics Olympiad each summer. Kirkpatrick is currently serving as vice president of the American Association of Physics Teachers and will serve as president-elect, president, and past president in 1998, 1999, and 2000, respectively. Kirkpatrick received a B.S. in physics from Washington State University in 1963 and a Ph.D. in experimental high-energy physics from MIT in 1968. He is an avid sports fan and loves country western dancing.*

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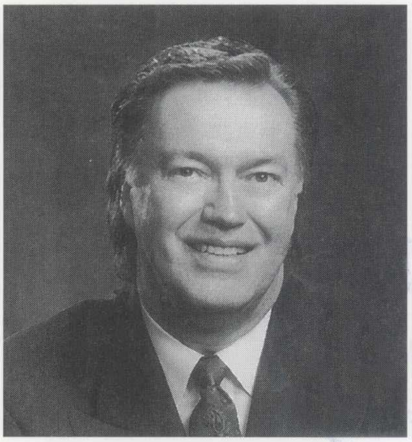


**Gerald F. Wheeler** *is executive director of the National Science Teachers Association. Prior to that he was professor of physics at Montana State University, director of MSU's Science/Math Resource Center, program director (Public Understanding of Science and Technology) at the American Association for the Advancement of Science, and professor of physics at Temple University. Wheeler received his B.S. in 1963 from Boston University with a major in science education and his Ph.D. at SUNY–Stony Brook in 1972 in experimental nuclear physics. Between undergraduate and graduate school, he taught high school physics. He enjoys cooking, photography, and old cars.*

# PHYSICS
# A World View

*third edition*

We dedicate this book to our five children—

*Jennifer, Monica, Solveiga, Soren, and Peter—*
*who in their very different ways have taught us how*
*to view the world again.*

# Preface

This textbook is intended for a conceptual course in introductory physics for students majoring in fields other than science, mathematics, or engineering.

Writing this book has been an exercise in translation. We have attempted to take the logic, vocabulary, and values of physics and communicate them in an entirely different language. In some areas the physics is so abstract that it took creative bridges to span the gulf between the languages. A good job of translating requires careful attention to both languages, that of the physicist and that of the student. We are indebted to the many students who shared their confusions with us and wrestled with the clarity of our translations. We are equally indebted to the many physicists who shared our search for the proper word or metaphor that comes closest to capturing the abstract, elusive idea.

Mathematics is the structural foundation for all of the physics world view. As stated above, this textbook translates most of the ideas into longer, less tightly structured sentences. Still, the mathematics holds much of the beauty and power of physics, and we want to offer a glimpse of this for students whose mathematical background is adequate. For that reason, we have written a mathematical supplement that delves deeper into the mathematical structure of the physics world view. A full description of the mathematical supplement, *Physics: A Numerical World View,* is given in the ancillary section of this preface.

## Objectives

The main objective of this physics textbook is to provide non-science-oriented students with a clear and logical presentation of some of the basic concepts and principles of physics in an appropriate language. Our overriding concern has been to choose topics and ideas for students who will be taking only this course in physics. We continually reminded ourselves that this may be our one chance to describe the way physicists look at the world and test their ideas. We chose topics that convey the essence of the physics world view. As an example of this concern, we have placed more modern physics—specifically the theories of relativity—in the first half of the book rather than toward the end, as in most traditional textbooks. We also describe the historical development of quantum physics carefully in order to show why various atomic models—models that make common sense—fail to explain the experimental evidence. At the same time, we have attempted to motivate students through practical examples that demonstrate the role of physics in other disciplines and in their everyday lives.

## Coverage

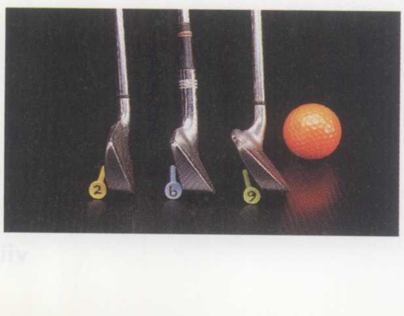
The topics covered in this book are the fundamental topics in classical and modern physics. The book is divided into nine parts. The first Interlude precedes Chapter 5. Each Interlude sets the theme for that section. Part I (Chapters 1–4) deals with the fundamentals of motion, ending with a careful look at gravity, our most familiar force. Part II (Chapters 5–6) reexamines motion through an investigation of two fundamental conservation laws: momentum and energy. In the beginning of Part III (Chapters 7–10), we set the stage for expanding our understanding of energy by investigating the structure of matter, first macroscopically, then microscopically. This part ends with heat and thermodynamics. Part IV (Chapters 11–13) explores the concepts involved in classical, special, and general relativity. Part V (Chapters 14–15) develops the basic properties of wave phenomena and applies them to a study of music. It also gives the reader a background that will be helpful in understanding much of quantum physics. Part VI (Chapters 16–18) covers the study of light and optics, starting with the general question of the basic nature of light, covering interesting applications, and ending with consequences of the wave nature of light. Part VII (Chapters 19–21) covers the basic concepts in electricity and magnetism. In Part VIII (Chapters 22–23) we develop the story of the quantum, starting with the discovery of the electron and ending with quantum physics. The final section of the textbook, Part IX (Chapters 24–26), takes the student deeper into the study of the structure of matter by looking at the nucleus and eventually the fundamental particles.

## New to the Third Edition

After soliciting comments from physics teachers and students, we carefully considered each suggestion and used many of them in reworking the entire text. We simplified explanations of some phenomena, updated developing areas, such as elementary particles and lasers, and added new explanatory material on the global positioning system, lasers, and reactions caused by collisions. There is also increased coverage of the physics of biology and medicine.

In order to make the text friendlier to those who prefer to skip over the more mathematical treatments, we've isolated this material into 25 Math Boxes. Care has been taken to allow readers to skip over these boxes without loss of continuity.

We have also reexamined each drawing for clarity and to see if it accomplished its intended functions. Twenty-one figures were modified or entirely redrawn to remove ambiguities or to make the meaning more transparent. Many of the photographs have been changed to improve their functionality. The legends for numerous illustrations and photographs have been rewritten or improved. Legends have been added to all chapter opening photographs.




To emphasize that physics is an evolving science, we have replaced the 16 Physics Updates with 31 new ones. These are released by the American Institute of Physics to science writers nationwide and highlight some of the advances in physics and related sciences that have taken place during the past three years.

The number of conceptual questions has been increased by 62 for a total of 1514. An additional 119 questions were replaced and 57 revised. The 504 exercises include 7 new, 21 replaced, and 245 revised.

## Thematic Paths

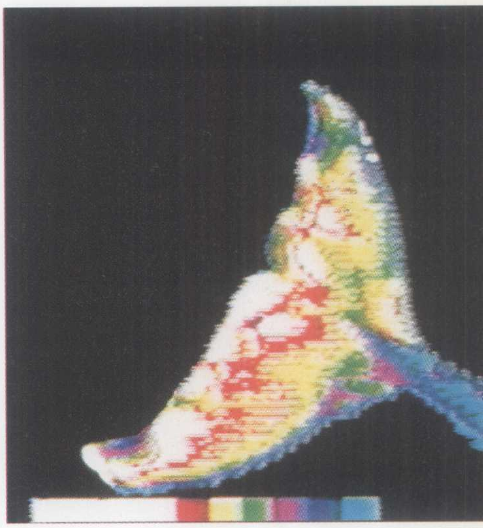
A big part of the flow of any course rests on decisions made by you. For this reason, the textbook contains more material than can be covered in an introductory course in one term. Even we teach the course differently. One of us likes to stress thermodynamics, while the other spends more time on optics. It is possible to take many routes through the material, depending on your interests and the interests of your students. To illustrate some possibilities, we have compiled seven different paths that can be used for semester-long courses. Each thematic path uses about one-half of the material presented in the text. These seven different emphases (or thematic paths) might be called Physical Science, Electricity and Magnetism, Optics, Energy, Vibrations and Waves, Relativity, and Elementary Particles.

*Physical Science* emphasizes those topics that are basic to both physics and chemistry. After studying motion and the concepts of momentum and energy, this emphasis delves into the structure and states of matter, heat and thermodynamics, the basic properties of waves, and ends up with atomic physics.

In the *Electricity and Magnetism* course, we begin with motion and the concepts of momentum and energy, skip to the chapter on waves, and then to the three chapters on electricity, magnetism, and electromagnetism. We conclude with the two chapters on atomic physics.

The *Optics* emphasis also begins with motion and waves. It then covers most of the three chapters on light and finishes with atomic physics.

The *Energy* course of study begins with motion, momentum, and mechanical energy. It then covers the two chapters on thermal energy and thermodynamics. After the chapter on waves, the course skips to the three chapters on electricity and magnetism, including electromagnetic waves. The course ends with a study of the nucleus and nuclear energy.



*Vibrations and Waves* covers motion and energy, and then concentrates on the wave properties of music, light, electromagnetism, and the quantum-mechanical atom.

The *Relativity* option yields a very different course. After a study of the basics of motion, momentum, and energy, the course includes the three chapters on classical, special, and general relativity. There are many ways to complete this course; we favor finishing with some of the properties of light.

For those interested in the search for the ultimate building blocks of the Universe, we suggest the *Elementary Particles* emphasis. The study of motion is followed by the chapter on the structure of matter. The amount of classical and special relativity will depend on the time you have. We then study waves and the wave aspect of light before moving on to selected topics in electricity. The main part of this course is the chapters on atomic and nuclear physics with elementary particles as the capstone.

We have detailed these seven theme-based courses in tabular form in the *Instructor's Resource Manual.*

## Features

Most instructors would agree that the textbook selected for a course should be the student's major "guide" for understanding and learning the subject matter. Furthermore, a textbook should be written and presented to make the material accessible and easier to teach, not harder. With these points in mind, we have included many pedagogical features to enhance the usefulness of our text for both you and your students.

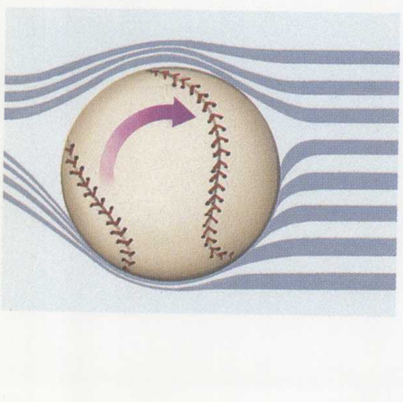
***Organization:*** The book contains a story line about the development of the current physics world view. It is divided into nine parts: the fundamentals of motion and gravity; the conservation laws of momentum and energy; the structure of matter, including heat and thermodynamics; the theories of relativity; wave phenomena and sound; light and optics; electricity and magnetism; the story of the quantum; and the nucleus and fundamental particles. Each part includes an overview of the subject matter to be covered in that part and some historical perspectives.

***Style:*** We have written the book in a style that is clear, logical, and succinct, in order to facilitate students' comprehension. The writing style is somewhat informal and relaxed, which we hope students will find appealing and enjoyable to read. New terms are carefully defined, and we have tried to avoid jargon.

***Mathematical Level:*** The mathematical level in the text has been kept to a minimum, with some limited use of algebra and geometry. Equations are presented in words as well as in symbols. For those desiring a higher mathematical presentation, we have written a mathematical supplement, *Physics: A Numerical World View.* The text is available shrink-wrapped with this ancillary.

We have not shied away from using numbers where they assist in developing a more complete understanding of a concept. On the other hand, we have rounded off the values of physical constants to help simplify the discussion. For example, we use 10 (meters per second) per second for the acceleration due to gravity, except when discussing the law of universal gravitation, where the additional accuracy is needed to understand the development.

***Math Boxes:*** More mathematical material has been placed into Math Boxes. These 25 boxed features allow those students following a more mathematical track to find them easily, while allowing others to skip over this mathematical material without loss of continuity. See, for example, "Computing Acceleration" on page 14, or "Computing Conservation of Kinetic Energy," on page 133.



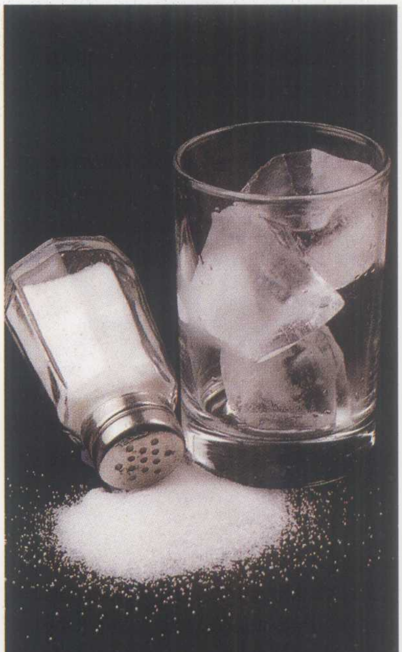
***Illustrations:*** The readability and effectiveness of the text material are enhanced by the large number of figures, diagrams, photographs, and tables. Full color is used to add clarity to the artwork and to make it realistic. For example, vectors are color-coded for each physical quantity. Three-dimensional effects are produced with the use of color and airbrushed areas, where appropriate. Many of the illustrations show the development of a phenomenon over time as a series of "snapshots." To illustrate the flow of time, we have added a *clock icon* in these drawings. The color photographs have been carefully selected, and their accompanying captions serve as an added instructional tool. A complete description of the pedagogical use of color appears at the front of the book.

***Chapter Opening Questions and Answers:*** Each chapter begins with an inquiry that is answered at the end of the chapter. These focus the student's attention on an important aspect of each chapter.

***In-text Questions:*** Questions to stimulate thinking are given at key spots throughout each chapter and are set off by a colored screen. These 187 questions allow students to immediately test their comprehension of the concepts discussed. The answers to these questions are in footnotes on the same page. Most questions could also serve as a basis for initiating classroom discussions.

***Conceptual Questions and Exercises:*** An extensive set of questions and exercises is included at the end of each chapter, with a total of 1514 questions and 504 exercises. The questions and exercises are presented in pairs, meaning that each even-numbered question or exercise has a similar odd-numbered one immediately preceding it. This arrangement allows the student to have one question or exercise with an answer in the back of the book and a very similar one without an answer. The pairing also allows you to discuss one exercise in class and assign its "partner" for homework. We have also included a small number of challenging questions and exercises, which are indicated by an asterisk printed next to the number. Answers to the odd-numbered questions and exercises are given at the end of the book. Answers to all questions and solutions to all exercises are included in the *Instructor's Resource Manual.*

***Physics on Your Own:*** Each chapter contains several projects and simple experiments for students to do on their own. The 91 projects have been designed to require a minimum of apparatus and to illustrate the concepts presented in the text. These illustrate the experimental aspects of physics and the application of physics to our everyday lives.



***Special Topics:*** All chapters include optional special topic boxes to expose students to various practical and interesting applications of physical principles. Some of the special topics include mirages, liquid crystal displays, fluorescent colors, holograms, gravity waves, radon, and superconductivity.

***Biographical Sketches:*** In addition to the historical perspectives provided in the eight Interludes between the major parts of the text, we have added short biographies of important scientists throughout the text to give a greater historical emphasis without interrupting the development of the physics concepts.


***Physics Updates:*** We have included 31 news releases known as *Physics Updates* to emphasize that physics is an evolving science. *Physics Updates* are released by the American Institute of Physics to science writers nationwide and highlight some of the advances in physics and related sciences that have taken place during the past three years. These news releases can serve as the starting points for independent studies by students.

***Important Concepts:*** Important statements and equations are highlighted in several ways for easy reference and review.

- Important principles and equations are boxed for easy reference.
- Marginal notes are used to highlight important statements, equations, and concepts in the text.
- Each chapter ends with a summary reviewing the important concepts of the chapter and the key terms. If terms introduced in previous chapters are reused, they are relisted for convenient reference.

***Units:*** The international system of units (SI) is used throughout the text. The British engineering system of units (conventional system) is used to a limited extent in the chapters on mechanics, heat, and thermodynamics to help the student develop a better feeling for the sizes of the SI units.

***Appendices:*** Three appendices are provided at the end of the text, one on the metric system, one on powers-of-ten notation, and one on the Nobel laureates in physics.

***Endpapers:*** Tables of physical data and other useful information, including fundamental constants and physical data, and standard abbreviations of units appear on the endpapers. In addition, the front endpaper includes the color code for all figures and diagrams.

## Ancillaries

The following ancillaries are available to accompany this text:

***Physics: A Numerical World View:*** This mathematical supplement, keyed to the text, looks at the development of the physics world view with more emphasis on mathematics. Sections that have an extended, parallel presentation in the mathematical supplement have the Σ symbol to the right of the section title. The supplement is available shrink-wrapped with the text at minimal cost.

***Instructor's Resource Manual:*** The *Instructor's Resource Manual* contains answers to all questions and solutions to all exercises in the text and all problems in the math supplement. Each chapter in this manual has teaching tips on each text section and additional information about integrating the Physics Demonstration Videotape or Videodisc in your course.

***Test Bank:*** To help you prepare quizzes and exams, the Test Bank provides over 1000 multiple-choice, short answer, numerical, and graphical questions covering every chapter in the text. Answers to all questions are included in the Test Bank.

***ExaMaster+™ Computerized Test Banks:*** The Test Bank is available in computerized form for IBM, Macintosh, and Windows users. The ExaMaster+™ Computerized Test Banks allow you to preview, select, edit, and add items to tailor tests to your course or select items at random, add or edit graphics, and print up to 99 different versions of the same test and answer sheet. ExamRecord™ gradebook software is available with the IBM® PC version.

***Overhead Transparency Acetates:*** The conceptual physics student often has difficulty gleaning all the information presented in physics diagrams. Therefore, a collection of 100 full-color transparency acetates of important figures from the text is available to adopters. These transparencies feature large print for easy viewing in the classroom.

***A World View of Environmental Issues:*** A popular ancillary distributed free to students when purchasing the text is an environmental supplement based on an NSF grant to the Temple University physics department. It explores the following topics from a basic physics perspective: (1) the scientific method, (2) how to research environmental issues using databases and the Internet, (3) nuclear power plants and nuclear waste disposal, (4) indoor air pollution including radon and sick building syndrome, (5) stratospheric ozone depletion and the greenhouse effect, (6) electromagnetic waves and effects on humans, and (7) the mass media and its portrayal of environmental issues.

***Physics Demonstration Videotape/Videodisc:*** J.C. Sprott of the University of Wisconsin, Madison, has prepared 1 3/4 hours of video demonstrating a wide variety of simple physics experiments. The 74 demonstrations are divided into 12 subject areas, covering the major topics in the introductory physics course. The *Instructor's Resource Manual for the Physics Demonstration Videotape* gives helpful hints about integrating the videotape into your lecture and replicating demonstrations. More information about correlating the video to the text is also available in the *Instructor's Resource Manual* to this text.

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## Acknowledgments

Physicists and physics teachers who gave freely of their time to explore the many options of explaining the physics world view with a minimum of mathematics include our colleagues John Carlsten, William Hiscock, Robert Swenson, and George Tuthill from Montana State University, as well as Arnold Arons (University of Washington), Larry Gould (University of Hartford), and Bob Weinberg (Temple University). We appreciate the special efforts of Montana State University photography graduate David Rogers for many of the photographs used in the text.

The following reviewers provided valuable input for the current revision:

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Jan Yarrison-Rice, *Miami University of Ohio*

Reviewers who played an important role in the development of the second edition of the text include:

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Reviewers of the first edition, who helped shape the content and structure of the current edition, include:

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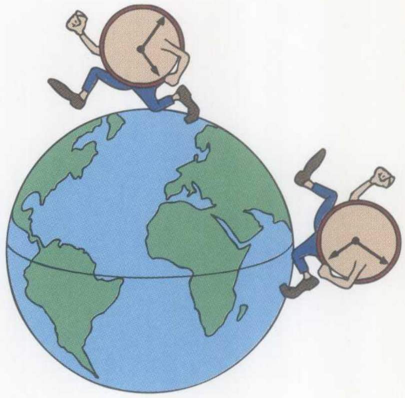
After giving serious consideration to each of the reviewers' suggestions, we made the final decisions and, therefore, accept the responsibility for any errors, omissions, and confusions that might remain in the text. We would, of course, appreciate receiving any comments that you might have. Send comments and suggestions to Larry D. Kirkpatrick, Physics, Montana State University, Bozeman MT 59717-3840 or via e-mail at kirkpatrick@physics.montana.edu.

Finally, we would like to thank the staff at Saunders, who brought a level of professionalism and enthusiasm for the challenge that we have never experienced before. Special thanks go to John Vondeling, Publisher; Marc Sherman, Senior Associate Editor; Anne Gibby, Senior Project Editor; Lisa Caro, Art Director; Dena Digilio-Betz, Photo Researcher; and George Kelvin for his beautiful illustrations.

**Larry D. Kirkpatrick**
**Gerald F. Wheeler**
*Montana State University*
*August 1997*

The publisher and authors have gone to great measures to ensure as error-free a text as is humanly possible. We are so confident of the success of this effort that we are offering $5.00 for any first time technical error you may find. Note that we will pay only for each error the first time it is brought to our attention. Also note that this offer is valid only for technical errors in physics—not questions of grammar or style, nor for typographer's errors. Please write to John Vondeling, Publisher, and include your social security number.

# To the Student



This course could be one of the most challenging experiences that you will ever have—except for first grade. But then you were too young to notice.

What happened in first grade? Well, you learned to read and that was really hard. First you had to learn the names of all those weird little squiggles. You had to learn to tell a *b* from a *d* from a *p*. Even though they looked so much alike, you did it, and it even seemed like fun. Then you learned the sounds each letter represented, and that was not easy because the capitals looked different but made the same sound, and some letters could have more than one sound.

Then one day your teacher put some letters on the board. First, the letter *C*, and you all knew it could make a Kuh or Suh. Then your teacher wrote the letter *A*. That had lots of possibilities. Finally, a *T*, which luckily had only one sound. You tried out several combinations including Kau-AAH-Tuh. Then suddenly someone shouted out in triumph, "That isn't kuh-aah-tuh! It's a small furry animal with a long skinny tail that says 'meow'." And your world was never the same again. When your car paused at an eight-sided red sign, you sounded out *stop* and understood how the drivers knew what to do. You saw the words *ice cream* on the front of a store and knew you wanted to go in.

If this book works, you will become aware of a whole world you never noticed before. You will never walk down a street, ride in a car, or look in a mirror without involuntarily seeing an extra dimension. There are times when you will have to memorize what symbols mean—just like in first grade. There will be times when you will confuse things that seem as much alike as *b*, *d*, and *p* once did, until you suddenly see how different they are. And there will be times when you will look at a combination of events and equations helplessly reciting Kuh-AAH-Tuh in total frustration. This has happened to all of us. But then the moment of insight will come, and you will see whole new images fitting together. You will see the *C-A-T* and will experience fully, and consciously, the exhilaration you felt in first grade.

So, welcome to one of the most challenging (and rewarding) courses you have ever taken in your life. If you work at it and let it happen, this experience will change your world view forever.

**Larry D. Kirkpatrick**
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*Bozeman, MT 59717*

Adapted from an article by Barbara Wolff, "An Introduction to Physics—Find the CAT." *The Physics Teacher* **27**, 427.

# Contents Overview