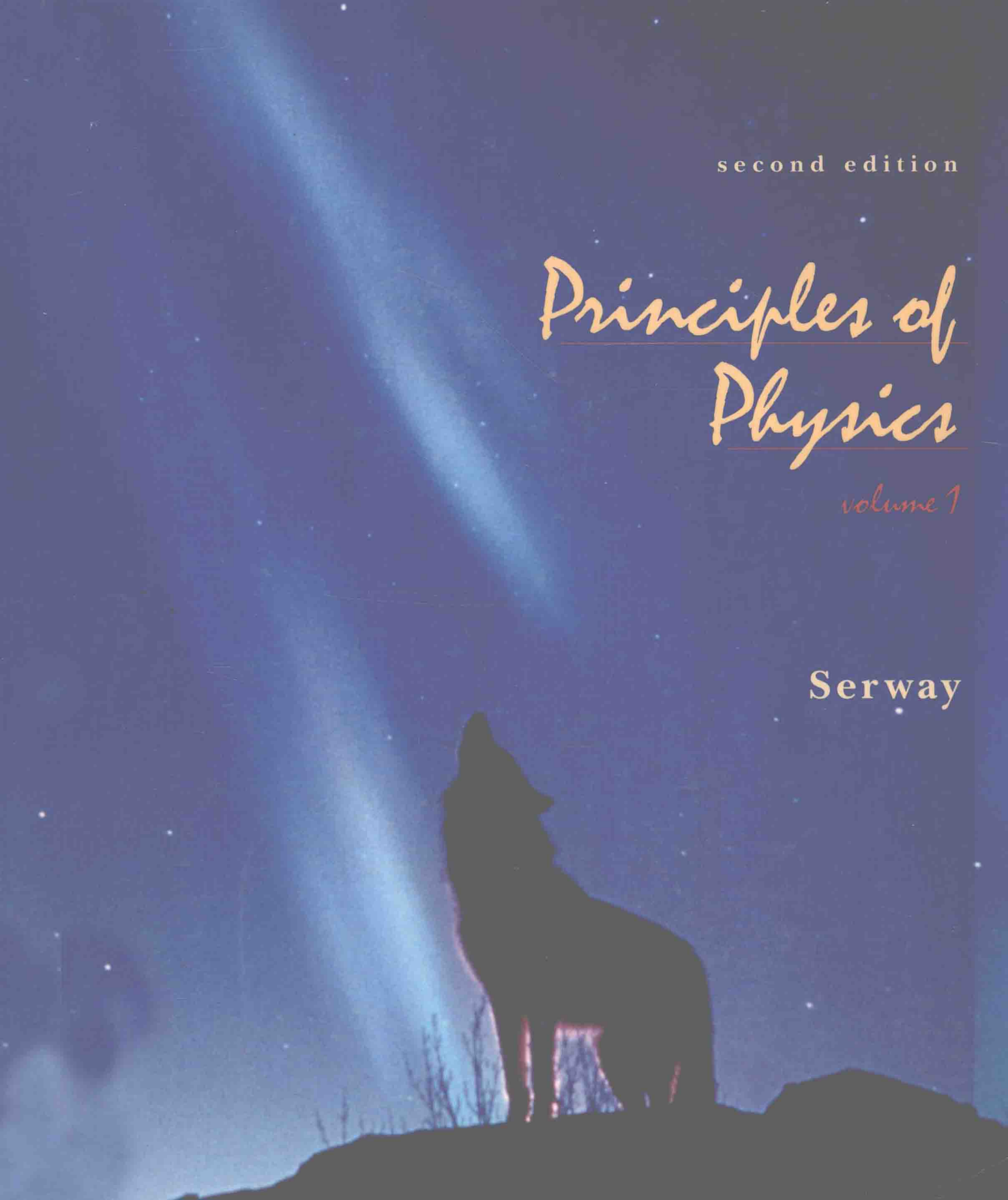
second edition

Principles of Physics

volume 1

Serway



Principles *of* Physics

SECOND EDITION

Volume 1

Raymond A. Serway

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with contributions by

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Some Fundamental Constants[a]

Quantity	Symbol	Value[b]
Atomic mass unit	u	$1.660\,540\,2(10) \times 10^{-27}$ kg 931.494 32(28) MeV/c^2
Avogadro's number	N_A	$6.022\,136\,7(36) \times 10^{23}$ $(\text{mol})^{-1}$
Bohr magneton	$\mu_B = \frac{e\hbar}{2m_e}$	$9.274\,015\,4(31) \times 10^{-24}$ J/T
Bohr radius	$a_0 = \frac{\hbar^2}{m_e e^2 k_e}$	$0.529\,177\,249(24) \times 10^{-10}$ m
Boltzmann's constant	$k_B = R/N_A$	$1.380\,658(12) \times 10^{-23}$ J/K
Compton wavelength	$\lambda_C = \frac{h}{m_e c}$	$2.426\,310\,58(22) \times 10^{-12}$ m
Deuteron mass	m_d	$3.343\,586\,0(20) \times 10^{-27}$ kg 2.013 553 214(24) u
Electron mass	m_e	$9.109\,389\,7(54) \times 10^{-31}$ kg $5.485\,799\,03(13) \times 10^{-4}$ u 0.510 999 06(15) MeV/c^2
Electron-volt	eV	$1.602\,177\,33(49) \times 10^{-19}$ J
Elementary charge	e	$1.602\,177\,33(49) \times 10^{-19}$ C
Gas constant	R	8.314 510(70) J/K·mol
Gravitational constant	G	$6.672\,59(85) \times 10^{-11}$ N·m^2/kg^2
Hydrogen ground state	$E_0 = \frac{m_e e^4 k_e^2}{2\hbar^2} = \frac{e^2 k_e}{2a_0}$	13.605 698(40) eV
Josephson frequency-voltage ratio	$2e/h$	$4.835\,976\,7(14) \times 10^{14}$ Hz/V
Magnetic flux quantum	$\Phi_0 = \frac{h}{2e}$	$2.067\,834\,61(61) \times 10^{-15}$ Wb
Neutron mass	m_n	$1.674\,928\,6(10) \times 10^{-27}$ kg 1.008 664 904(14) u 939.565 63(28) MeV/c^2
Nuclear magneton	$\mu_n = \frac{e\hbar}{2m_p}$	$5.050\,786\,6(17) \times 10^{-27}$ J/T
Permeability of free space	μ_0	$4\pi \times 10^{-7}$ N/A^2 (exact)
Permittivity of free space	$\epsilon_0 = 1/\mu_0 c^2$	$8.854\,187\,817 \times 10^{-12}$ C^2/N·m^2 (exact)
Planck's constant	h $\hbar = h/2\pi$	$6.626\,075(40) \times 10^{-34}$ J·s $1.054\,572\,66(63) \times 10^{-34}$ J·s
Proton mass	m_p	$1.672\,623(10) \times 10^{-27}$ kg 1.007 276 470(12) u 938.272 3(28) MeV/c^2
Quantized Hall resistance	h/e^2	25812.805 6(12) Ω
Rydberg constant	R_H	$1.097\,373\,153\,4(13) \times 10^7$ m^{-1}
Speed of light in vacuum	c	$2.997\,924\,58 \times 10^8$ m/s (exact)

[a] These constants are the values recommended in 1986 by CODATA, based on a least-squares adjustment of data from different measurements. For a more complete list, see Cohen, E. Richard, and Barry N. Taylor, *Rev. Mod. Phys.* **59:**1121, 1987.

[b] The numbers in parentheses for the values below represent the uncertainties in the last two digits.

Principles of Physics

SECOND EDITION

Volume 1

Preface

Principles of Physics is designed for a one-year introductory calculus-based physics course for engineering and science students. This second edition contains many new pedagogical features—most notably, an increased emphasis on physical concepts through the use of conceptual examples and conceptual problems. Based on comments from users of the first edition and reviewers' suggestions, a major effort was made to improve organization, clarity of presentation, precision of language, and accuracy throughout.

This project was conceived because of the well-known problem we continue to wrestle with in teaching the introductory calculus-based physics course. The course content (and hence the size of textbooks) continues to grow, while the number of contact hours with students has either dropped or remained unchanged. Furthermore, traditional one-year courses cover little if any 20th-century physics.

In preparing this book, I was motivated by the spreading interest in reforming this course, primarily through efforts of the Introductory University Physics Project (IUPP) sponsored by the American Association of Physics Teachers and American Institute of Physics. The primary goals and guidelines of this project are to:

- reduce course content following the "less may be more" theme
- incorporate contemporary physics naturally into the course
- organize the course in the context of one or more "story lines"
- treat all student constituents equitably

Bruce Byers, FPG

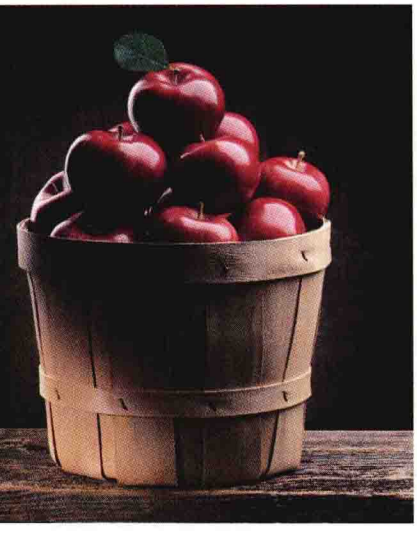
Recognizing a need for a textbook that could meet these guidelines several years ago, I studied the various proposed IUPP models and the many reports from IUPP committees. Eventually, I became actively involved in the review and planning of one specific model, initially developed at the U.S. Air Force Academy, entitled "A Particles Approach to Introductory Physics." I spent part of the summer of 1990 at the Academy working with Colonel

James Head and Lt. Col. Rolf Enger, the primary authors of the IUPP model, and other members of that department. This most useful collaboration was the starting point of this project.

In my opinion, the IUPP model developed at the U.S. Air Force Academy, and modified by a team of people over the last few years, was an excellent choice for designing a reformed curriculum for several reasons:

- It is an evolutionary approach (rather than a revolutionary approach), which should meet the current demands of the physics community.
- It deletes many topics in classical physics (such as alternating current circuits and optical instruments), and places less emphasis on rigid body motion, optics, and thermodynamics.
- Some topics in 20th century physics are introduced early in the textbook such as special relativity, energy and momentum quantization, and the Bohr model of the hydrogen atom.
- A deliberate attempt is made at showing the unity of physics.

CHANGES TO THE SECOND EDITION



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A number of changes and improvements have been made in the second edition of this text. Many changes are in response to comments and suggestions provided by reviewers of the manuscript and instructors using the first edition. The following represent the major changes in the second edition:

Organization The organization of the textbook is slightly different from that of the first edition. Chapter 6 in the first edition has been deleted, and the sections dealing with the fundamental forces in nature and the gravitational field are now incorporated in Chapter 5. The material on oscillatory motion and waves (Chapters 21, 22, and 23 in the first edition) is now covered earlier (Chapters 12, 13, and 14 in the second edition), following mechanics. The two chapters in the first edition covering interference and diffraction of light waves (Chapters 27 and 28) have been combined and condensed into one chapter entitled Wave Optics (Chapter 27). The section on polarization of light waves is now treated earlier in Chapter 24 entitled Electromagnetic Waves. The section on fission and fusion in Chapter 10 of the first edition has been moved to Chapter 30 entitled Nuclear Physics. Finally, by popular demand, Chapter 15 entitled Fluid Mechanics is new to this edition.

Content In this second edition, a concerted effort was made to place more emphasis on critical thinking and teaching physical concepts. This was accomplished by the addition of approximately 150 conceptual examples, called **Thinking Physics,** and over 200 **Conceptual Problems.** Most of the **Thinking Physics** examples, which include reasoning statements, provide students with a means of reviewing the concepts presented in that section. Some examples demonstrate the connection between the content of that chapter and other scientific disciplines. These examples also serve as models for students to respond to the **Conceptual Problems** posed in the text and end-of-chapter conceptual questions. The answers to all **Conceptual Problems** are contained at the end of each chapter.

Problems and Conceptual Questions A substantial revision of the end-of-chapter problems and conceptual questions was made in this second edition. Most of the new problems that have been added are intermediate in level, and many of them are problems that require students to make order-of-magnitude calculations or estimates. All problems have been carefully edited and reworded where necessary. Solutions to approximately 25 percent of the end-of-chapter problems and selected conceptual questions are included in the Study Guide and Student Solutions Manual. These problems and questions are identified by boxes around their numbers.

Significant Figures Significant figures in both worked examples and end-of-chapter problems have been handled with care. Most numerical examples and problems are worked out to three significant figures.

TEXTBOOK FEATURES

The textbook includes many features which are intended to enhance its usefulness to both the student and instructor:

Style I have attempted to write the book in a style that is clear, logical, and succinct. At the same time, my relaxed writing style is meant to make the reading more enjoyable and less intimidating.

Previews Most chapters begin with a chapter preview, which includes a brief discussion of chapter objectives and content. This feature enables the student to better understand how the topics covered in that chapter fit into the overall structure and objectives of the course.

Mathematical Level Calculus is introduced gradually, where it is needed, keeping in mind that many students often take a course in calculus concurrently. Most steps are shown when basic equations are developed, and reference is made to mathematical appendices provided at the end of the text. Vector products are covered where they are needed in physical applications.

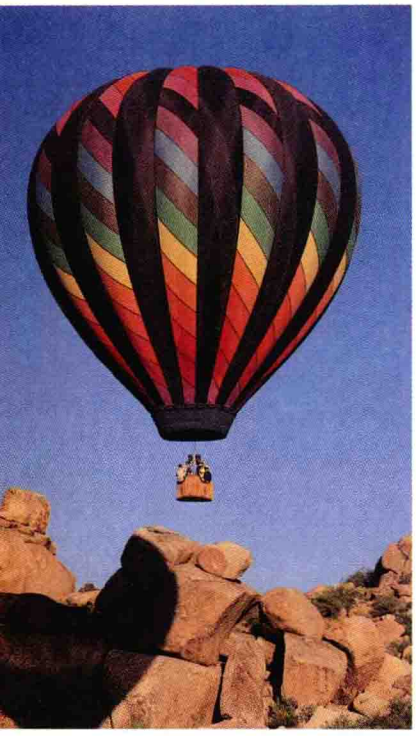
Conceptual Examples and Problems As mentioned earlier, one of the objectives of this edition is to place more emphasis on critical thinking and conceptual understanding. To meet this objective, I have included many **Thinking Physics** examples and **Conceptual Problems** throughout each chapter. The reasoning or responses to all examples immediately follow the example statement, while the answers to all conceptual problems are included at the end of each chapter. Ideally, the student will use these features to better understand physical concepts before being presented with quantitative examples and working homework problems.

Worked Examples Every chapter includes several worked examples of varying difficulty which are intended to reinforce conceptual understanding and to serve as models for solving end-of-chapter problems.

Exercises Many examples are followed immediately by exercises with answers. Those exercises contained in an example box represent extensions of the worked examples. Other related exercises with answers are included at the end of many

sections. All exercises are intended to encourage students to practice problem solving for immediate reinforcement, and to test the student's understanding of concepts and problem-solving skills. Students who work through these exercises on a regular basis should find the end-of-chapter problems less intimidating.

Important Statements and Equations Most important statements and definitions are set in **boldface** type for added emphasis and ease of review. Important equations are highlighted with a tan screen for review or reference.



Russell Schlepman

Illustrations The text material, worked examples, and end-of-chapter questions and problems are accompanied by numerous figures, photographs, and tables. Full color is used to add clarity to the figures and to make the visual presentations as realistic as possible. Three-dimensional effects are produced with the use of color airbrushed areas, where appropriate. Vectors are color-coded, and curves in *xy*-plots are drawn in color. Color photographs have been carefully selected, and their accompanying captions have been written to serve as an added instructional tool.

Margin Notes Margin notes are used to help students locate and review important statements, concepts, and equations.

Units The international system of units (SI) is used throughout the text. The British engineering system of units is used only to a limited extent in chapters on mechanics, heat, and thermodynamics.

Problem-Solving Strategies and Hints I have included general strategies and hints for solving the types of problems featured in both the worked examples and in the end-of-chapter problems. This feature will help students identify important steps and understand the logic for solving specific classes of problems.

Summaries Each chapter contains a summary which reviews the important concepts and equations discussed in that chapter.

Conceptual Questions A list of conceptual questions is provided at the end of each chapter. These questions, which require verbal or written responses, provide the student with a means of self-testing the concepts presented in the chapter. Others could serve as a basis for initiating classroom discussions. Answers to selected questions, indicated by boxes around their numbers, are included in the Study Guide and Student Solutions Manual.

End-of-Chapter Problems An extensive set of problems is included at the end of each chapter. Answers to odd-numbered problems are given at the end of the book; these pages have colored edges for ease of location. For the convenience of both the student and the instructor, about two thirds of the problems are keyed to specific sections of the chapter. The remaining problems, labeled "Additional Problems," are not keyed to specific sections. There are three levels of problems according to their level of difficulty. Straightforward problems are numbered in black, intermediate level problems are numbered in blue, and the most challenging problems are numbered in magenta.

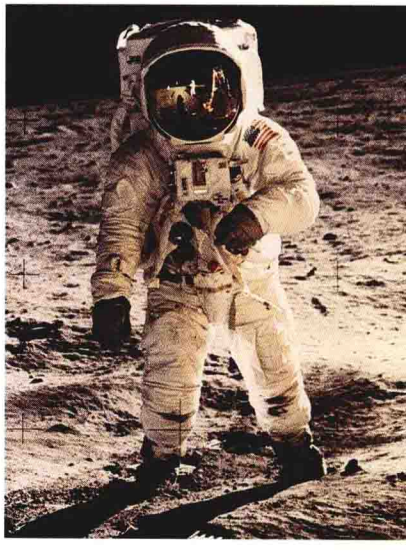
Spreadsheet Problems Most chapters include several spreadsheet problems following the end-of-chapter problem sets. Spreadsheet modeling of physical phenomena enables the student to obtain graphical representations of physical phenomena and perform numerical analyses without the burden of having to learn a high-level computer language. Spreadsheets are particularly useful in exploratory investigations; "what if" questions can be addressed easily and depicted graphically.

The level of difficulty in the spreadsheet problems, as with all end-of-chapter problems, is indicated by the color of the problem number. For the most straightforward problems (black), a disk with spreadsheet problems is provided. The student must enter the pertinent data, vary the parameters, and interpret the results. Intermediate level problems (blue) usually require students to modify an existing template to perform the required analysis. The more challenging problems (magenta) require students to develop their own spreadsheet templates. Brief instructions on using the templates are provided in Appendix E.

Appendices and Endpapers Several appendices are provided at the end of the textbook, including the new appendix with instructions for problem-solving with spreadsheets. Most of the appendix material represents a review of mathematical techniques used in the text, including scientific notation, algebra, geometry, trigonometry, differential calculus, and integral calculus. Reference to these appendices is made throughout the text. Most mathematical sections include worked examples and exercises with answers. In addition to the mathematical reviews, the appendices contain tables of physical data, conversion factors, atomic masses, the SI units of physical quantities, and the periodic chart. The endpapers contain other useful information including the color code used in the text, lists of fundamental constants and physical data, conversions, and the Greek alphabet.

SAUNDERS CORE CONCEPTS IN PHYSICS CD-ROM

Saunders Core Concepts in Physics CD-ROM applies the power of multimedia to the calculus-based course, offering unparalleled full-motion animation and video, engaging interactive graphics, clear and concise text, and guiding narration. *Saunders Core Concepts in Physics* focuses on those concepts students typically find most difficult in the course, drawing from mechanics, thermodynamics, electromagnetism, and optics. The CD-ROM also presents step-by-step explorations of essential mathematics, problem-solving strategies, and animations of problems to promote conceptual understanding and sharpen problem-solving skills. Problems on this CD-ROM are taken directly from Serway's *Principles of Physics*, 2/e. Available for Macintosh and Windows.



Courtesy of NASA

STUDENT ANCILLARIES

Study Guide and Student Solutions Manual by John R. Gordon, Ralph McGrew, Steve Van Wyk, and Ray Serway. The manual features detailed solutions to 25 percent of the end-of-chapter problems and selected conceptual questions from the text. These are indicated in the text with boxed numbers. The manual also features a skills section, important notes from key sections of the text, and a list of important equations and concepts.

Spreadsheet Templates The Spreadsheet Template Disk contains spreadsheet files designed to be used with the end-of-chapter problems entitled Spreadsheet Problems. The files have been developed in Microsoft Excel 5.0 for the Macintosh, and in several formats for Windows and DOS users (see Appendix E). These can be used with most spreadsheet programs including all the recent versions of Lotus 1-2-3, Excel for Windows, Quattro Pro, and f(g) Scholar. Over 30 templates are provided on the disk.

Spreadsheet Investigations in Physics by Lawrence B. Golden and James R. Klein. This workbook with the accompanying disk illustrates how spreadsheets can be used for solving many physics problems. The workbook is divided into two parts. The first part consists of spreadsheet tutorials, while the second part is a short introduction to numerical methods. The tutorials include basic spreadsheet techniques and emphasize navigating the spreadsheet, entering data, constructing formulas, and graphing. The numerical methods include differentiation, integration, interpolation, and the solution of differential equations. Many examples and exercises are provided. Step-by-step instructions are given for constructing numerical models of selected physics problems. The exercises and examples used to illustrate the numerical methods are chosen from introductory physics and mathematics.

Pocket Guide by V. Gordon Lind. This 5″ by 7″ notebook is a section-by-section capsule of the textbook that provides a handy guide for looking up important concepts, formulas, and problem-solving hints.

Mathematical Methods for Introductory Physics with Calculus by Ronald C. Davidson. This brief book is designed for students who find themselves unable to keep pace in their physics class because of a lack of familiarity with the necessary mathematical tools. *Mathematical Methods* provides an overview of those mathematical topics that are needed in an introductory-level physics course through the use of many worked examples and exercises.

So You Want to Take Physics: A Preparation for Scientists and Engineers by Rodney Cole. This text is useful to those students who need additional preparation before or during a course in physics. The book includes typical problems with worked solutions, and a review of techniques in mathematics and physics. The friendly, straightforward style makes it easier to understand how mathematics is used in the context of physics.

Life Science Applications for Physics compiled by Jerry Faughn. This supplement provides examples, readings, and problems from the biological sciences as they relate to physics. Topics include "Friction in Human Joints," "Physics of the Human Circulatory System," "Physics of the Nervous System," and "Ultrasound and Its Applications." This supplement is useful in those courses having a significant number of pre-med students.

Physics Laboratory Manual by David Loyd supplements the learning of basic physical principles while introducing laboratory procedures and equipment. Each chapter of the laboratory manual includes a pre-laboratory assignment, a list of objectives, an equipment list, the theory behind the experiment, the experimental

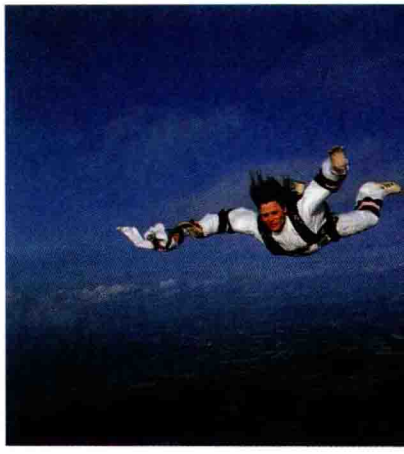
procedure to be followed, calculations, graphs, and questions. In addition, laboratory report templates are provided for each experiment so the student can record data, calculations, and experimental results.

INSTRUCTOR ANCILLARIES

Instructor's Solutions Manual by Steve Van Wyk, Ralph McGrew, and Ray Serway. This manual contains solutions to all of the problems in the text and provides answers to even-numbered problems. All solutions have been carefully reviewed for accuracy.

Printed Test Bank by Myron Schneiderwent. This test bank offers over 1500 multiple choice and conceptually oriented critical thinking questions.

Computerized Test Bank Available for the IBM PC (DOS and Windows) and Macintosh computers, this computerized version of the printed test bank also contains over 1500 questions. The test bank enables the instructor to create unique tests and permits the editing of questions as well as addition of new questions. The program gives answers to all problems and prints each answer on a separate grading key.



Guy Sauvage, Photo Researchers, Inc.

Overhead Transparency Acetates A set of 175 transparencies with approximately 300 full-color figures from the text.

Instructor's Manual to Accompany Physics Laboratory Manual by David Loyd. Each chapter contains a discussion of the experiment, teaching hints, answers to selected questions, and a post-laboratory quiz with short answer and essay questions. Also included is a list of suppliers of scientific equipment and a summary of all the equipment needed for the laboratory experiments in the manual.

Physics Demonstrations Videotape by J. C. Sprott. This video features two hours of demonstrations divided into 12 primary topics. Each topic contains between four and nine demonstrations for a total of 70 physics demonstrations.

Web Site Instructors adopting *Principles of Physics* may access the Instructor's Home Page on the World Wide Web at the URL

http://www.saunderscollege.com/physics/principles/

provided the proper password is given. Instructors will find a listing of overhead transparencies by chapter, a chapter-by-chapter guide to relevant experiments in *Physics Laboratory Manual*, 2nd edition by David Loyd, a correlation guide between chapters in *Principles of Physics* and the *Saunders Core Concepts in Physics* CD-ROM, and a link to the Student Home Page. Due to the fluid and changing nature of the World Wide Web, items may be added to this site or modified in the future.

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TEACHING OPTIONS

Although many topics found in traditional textbooks have been omitted from this textbook, instructors may find that the current text still contains more material than can be covered in a two-semester sequence. For this reason, I would like to offer the following suggestions. If you wish to place more emphasis on contemporary topics in physics, you should consider omitting parts or all of Chapters 15, 16, 17, 18, 24, 25, and 26. On the other hand, if you wish to follow a more traditional approach which places more emphasis on classical physics, you could omit Chapters 9, 11, 28, 29, 30, and 31. Either approach can be used without any loss in continuity. Other teaching options would fall somewhere in between these two extremes by omitting the sections labeled "Optional."

ACKNOWLEDGMENTS

As any author well knows, a project of this magnitude would be an impossible task without the assistance of many talented and dedicated individuals whose comments, criticisms, and suggestions are so important in developing a finished product. In preparing the second edition of this textbook, I have been guided by the expertise of many people who reviewed part or all of the manuscript. Special thanks go to John Jewett, Jr., Ron Bieniek, and Ralph McGrew who provided in-depth reviews of parts or all of the manuscript at various stages and offered many suggestions for its improvement. Laurent Hodges wrote several new end-of-chapter problems. I am most grateful to the following reviewers of the manuscript for their valuable feedback:

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Some end-of-chapter problems in Chapters 3, 6, and 8 of this second edition came from *University Physics,* 2nd edition by Alvin Hudson and Rex Nelson (Saunders College Publishing, 1990) or from *University Physics,* 2nd edition by George Arfken, David Griffing, Donald Kelly and Joseph Priest (Harcourt Brace Jovanovich, 1989). I thank the authors of these problems.

I am indebted to Colonel James Head and Lt. Col. Rolf Enger of the U.S. Air Force Academy for inspiring me to begin work on this project while I was at the Academy during the summer of 1990, and for their warm hospitality during my visit. They and their colleagues designed the original IUPP model upon which this textbook is based. Special thanks go to Ralph McGrew for assembling the problem sets, writing new problems, and checking solutions to all problems. I appreciate the tedious work of Ralph McGrew and Steve Van Wyk in writing the Instructor's Solutions Manual, and I thank Gloria Langer for her fine work in preparing this manual. I am grateful to John R. Gordon, Ralph McGrew, and Steve Van Wyk who co-authored the Study Guide and Student Solutions Manual, and to Linda Miller and Michael Rudmin for their assistance in its preparation. Dena Digilio-Betz was very helpful in locating many of the photographs used in this text. During the development of this text, I benefited from many useful discussions with my colleagues and other physics instructors including Robert Bauman, Don Chodrow, Jerry Faughn, John R. Gordon, Kevin Giovanetti, Dick Jacobs, Clem Moses, Dorn Peterson, Joseph Rudmin, and Gerald Taylor. I owe a debt of gratitude to Irene Nunes for clarifying much of the material in the first edition, and for eliminating many inconsistencies, redundancies, and other nightmares that authors must face. Special thanks and recognition go to the professional staff at Saunders College Publishing for their careful attention to detail and for their dedication to producing first quality textbooks, especially Susan Dust Pashos, Beth Ahrens, Alexandra Buczek, Sally Kusch, Carol Bleistine, and Angus McDonald. I sincerely appreciate

Michel Gouverneur, Photo News, Gamma Sport

the wisdom and enthusiasm of my publisher and good friend John Vondeling, who continues to publish high quality instructional products for science education.

Finally, I thank my entire family for their endless love, understanding, and continued encouragement, especially my beautiful and devoted wife Elizabeth, who is always at my side to share my joys and sorrows.

Ray Serway
Harrisonburg, VA

JANUARY 1997

To the Student

I feel it is appropriate to offer some words of advice which should be of benefit to you, the student. Before doing so, I will assume that you have read the Preface, which describes the various features of the text that will help you through the course.

HOW TO STUDY

Very often instructors are asked "How should I study physics and prepare for examinations?" There is no simple answer to this question, but I would like to offer some suggestions based on my own experiences in learning and teaching over the years.

First and foremost, maintain a positive attitude towards the subject matter, keeping in mind that physics is the most fundamental of all natural sciences. Other science courses that follow will use the same physical principles, so it is important that you understand and be able to apply the various concepts and theories discussed in the text.

Robin Smith/Tony Stone Images

CONCEPTS AND PRINCIPLES

It is essential that you understand the basic concepts and principles *before* attempting to solve assigned problems. This is best accomplished through a careful reading of the textbook before attending your lecture on that material. In the process, it is useful to jot down certain points which are not clear to you. Take careful notes in class, and then ask questions pertaining to those ideas that require clarification. Keep in mind that few people are able to absorb the full meaning of scientific material after one reading. Several readings of the text and notes may be necessary. Your lectures and laboratory work should supplement the text and clarify some of the more difficult material. You should reduce memorization of material to a minimum. Memorizing passages from a text, equations, and derivations does not necessarily mean you understand the material. Your understanding of the material will be enhanced through a combination of efficient study habits, discussions with other students and instructors,