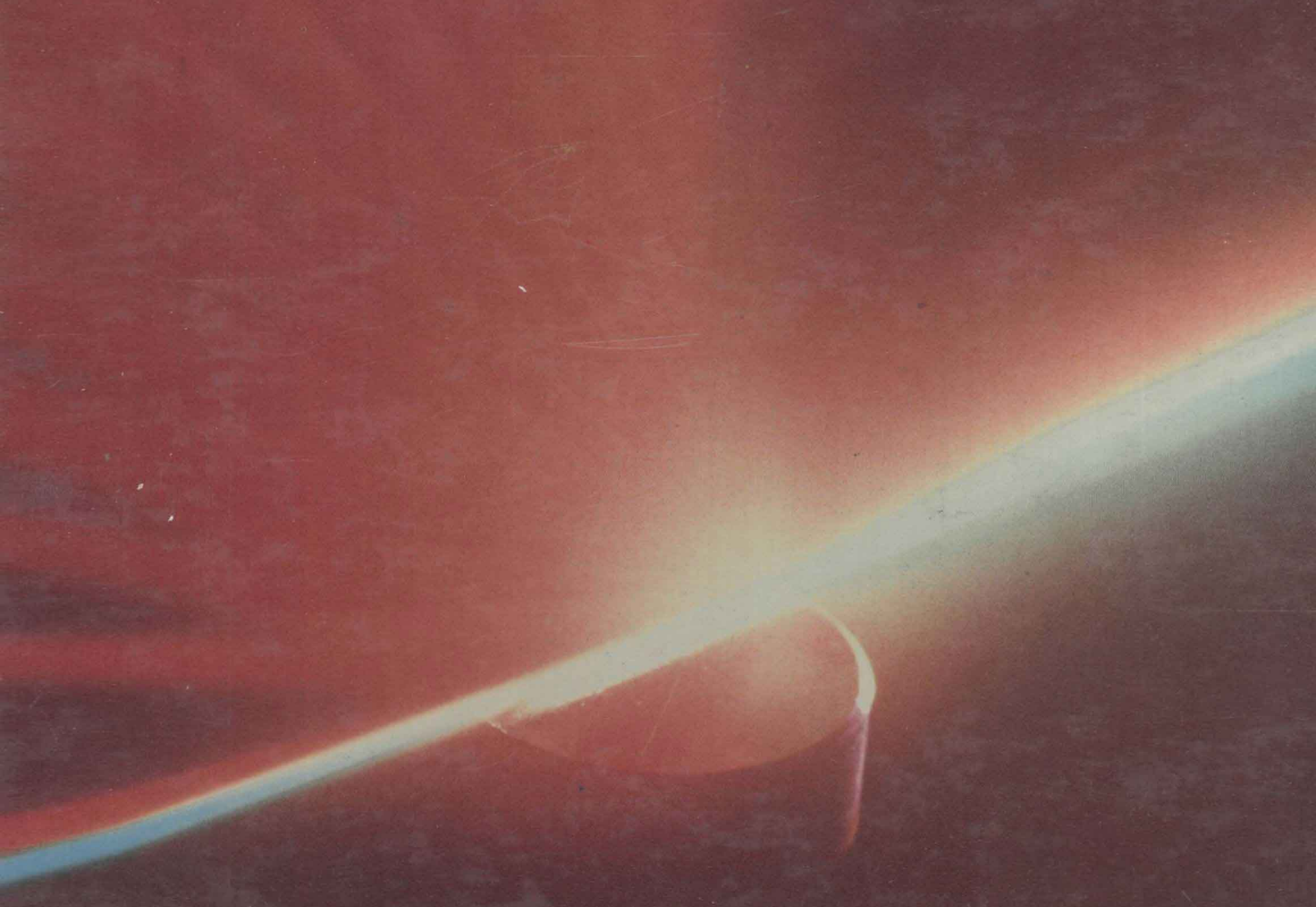
Physics
FOR
SCIENTISTS & ENGINEERS

SECOND EDITION



SERWAY

PHYSICS

FOR SCIENTISTS & ENGINEERS

2nd edition

Raymond A. Serway
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To my wife, Elizabeth Ann, and children, Mark, Michele, David and the most recent light in my life, Jennifer Lynn, for their love and understanding.

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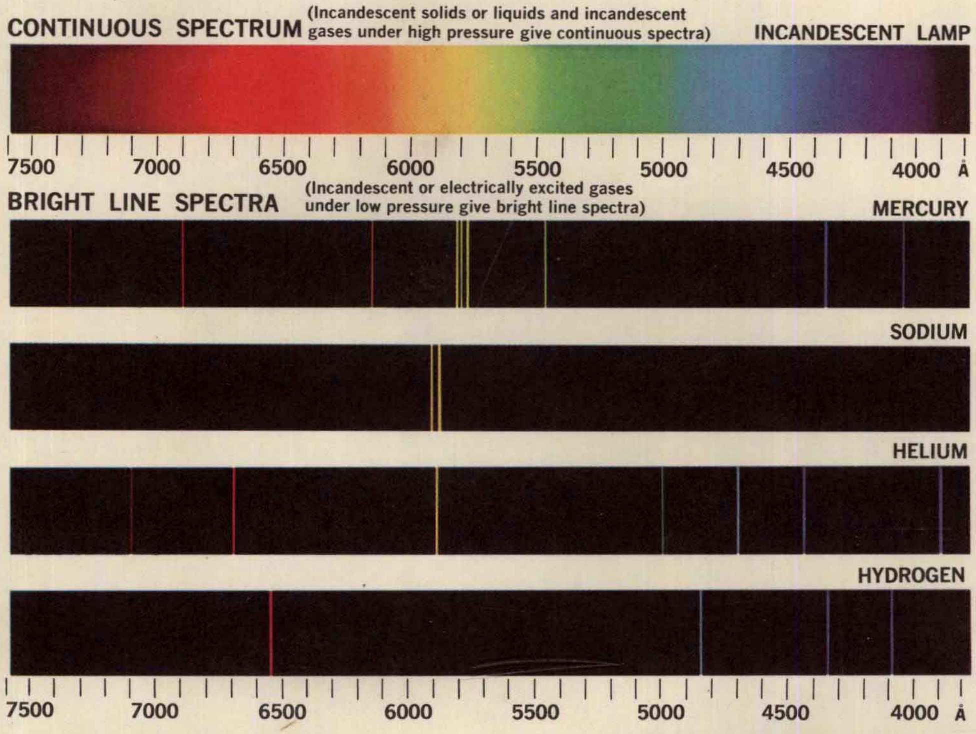
Some Fundamental Constants

Quantity	Symbol	Value
Atomic mass unit	u	$1.660\ 565\ 5(86) \times 10^{-27}$ kg $931.501\ 6(26)$ MeV/c^2
Avogadro's number	N_A	$6.022\ 045\ (31) \times 10^{23}$ (g mol)$^{-1}$
Bohr magneton	$\mathfrak{M}_s = \dfrac{e\hbar}{2m_e}$	$9.274\ 078\ (36) \times 10^{-24}$ A · m^2
Bohr radius	$r_0 = \dfrac{\hbar^2}{m_e e^2 k}$	$0.529\ 177\ 06(44) \times 10^{-10}$ m
Boltzmann's constant	$k = R/N_A$	$1.380\ 662\ (44) \times 10^{-23}$ J/K
Compton wavelength	$\lambda_C = \dfrac{h}{m_e c}$	$2.426\ 308\ 9(40) \times 10^{-12}$ m
Deuteron mass	m_d	$3.343\ 637 \times 10^{-27}$ kg $2.013\ 553\ 215\ (21)$ u
Electron charge	e	$1.602\ 189\ 2(46) \times 10^{-19}$ C
Electron mass	m_e	$9.109\ 534\ (47) \times 10^{-31}$ kg $5.485\ 802\ 6(21) \times 10^{-4}$ u $0.511\ 003\ 4(14)$ MeV/c^2
Electron-volt	eV	$1.602\ 189\ 2(46) \times 10^{-19}$ J
Gas constant	R	$8.314\ 41(26)$ J/K · mol
Gravitational constant	G	6.672×10^{-11} N · m^2/kg^2
Hydrogen ground state	$E_0 = \dfrac{m_e e^4 k^2}{2\hbar^2} = \dfrac{e^2 k}{2r_0}$	$13.605\ 804(36)$ eV
Neutron mass	m_n	$1.674\ 954\ 3(86) \times 10^{-27}$ kg $1.008\ 665\ 012(37)$ u $939.573\ 1(27)$ MeV/c^2
Nuclear magneton	$\mathfrak{M}_n = \dfrac{e\hbar}{2m_p}$	$5.050\ 824(20) \times 10^{-27}$ A · m^2
Permeability of free space	μ_0	$4\pi \times 10^{-7}$ N/A^2
Permittivity of free space	ϵ_0	8.8542×10^{-12} C^2/N · m^2
Planck's constant	h $\hbar = h/2\pi$	$6.626\ 176\ (36) \times 10^{-34}$ J · s $1.054\ 588\ (57) \times 10^{-34}$ J · s
Proton mass	m_p	$1.672\ 648\ 5(86) \times 10^{-27}$ kg $1.007\ 276\ 470\ (11)$ u $938.279\ 6(27)$ MeV/c^2
Rydberg constant	R	$1.097\ 373\ 177\ (83) \times 10^7$ m^{-1}
Speed of light in vacuum	c	$2.997\ 924\ 58(1.2) \times 10^8$ m/s

Report of the CODATA Task Group on Fundamental Constants, CODATA Bulletin, December 1973. See also E. R. Cohen and B. N. Taylor, *Journal of Physics and Chemistry*, Ref. Data 2, pp. 663–734, 1973.

EMISSION SPECTRA



Adapted from the SPECTRUM CHART, Welch Scientific Company

Physical Data Often Used[a]

Acceleration due to gravity	$9.80\ m/s^2$
Average earth-moon distance	3.84×10^8 m
Average earth-sun distance	1.49×10^{11} m
Average radius of the earth	6.37×10^6 m
Density of air	$1.29\ kg/m^3$
Density of water (20°C and 1 atm)	$1.00 \times 10^3\ kg/m^3$
Mass of the earth	5.99×10^{24} kg
Mass of the moon	7.36×10^{22} kg
Mass of the sun	1.99×10^{30} kg
Standard atmospheric pressure	1 atm = 1.013×10^5 Pa

[a] These are the values of the constants as used in the text.

PHYSICS

FOR SCIENTISTS & ENGINEERS

2nd edition

PREFACE

This textbook is intended for a two- or three-semester course in introductory physics for students majoring in science or engineering. The mathematical background of the student taking this course should ideally include at least one semester of calculus. If that is not possible, the student should be enrolled in a concurrent course in introductory calculus.

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

1. The order of topics has been changed slightly so that the chapters on wave motion and sound now follow the material on Newtonian mechanics, and hence precede the chapters dealing with electricity and magnetism.

2. An extensive amount of rewriting was done on the chapters concerned with light and optics, the chapter on *ac* circuits, and the chapters dealing with rotational dynamics. The chapter entitled "Magnetism in Matter" was combined with the chapter entitled "Sources of the Magnetic Field," and was reduced in its coverage. Chapter 6 was rewritten so as to emphasize application of Newton's second law to circular motion and motion through a viscous medium. Most of the material concerning the Universal Law of Gravity now appears in Chapter 14.

3. The book now contains 644 thought questions requiring verbal answers, an increase of about 100 over the first edition. All questions are now located near the end of each chapter following the summaries. New problems have also been added to the book for a total of 2009, a significant increase over the first edition. Many of the original problems have been revised and edited. Furthermore, all end-of-chapter problems are now designated as problems. (The previous separation into exercises and problems caused some confusion.) About ⅔ of the problems are keyed to specific sections, and an attempt has been made to place the more difficult problems near the end of a section group. The remaining problems, labeled "General Problems," are not keyed to any section. The more challenging problems are preceded by a bullet (•). A number of problems requiring the use of either a programmable calculator or a computer have been added to those chapters which are appropriate for such computations.

4. The artwork in the book is substantially new, as is the physical layout. A second color has been added to improve the clarity and effectiveness of the figures. Airbrushing has been used in those figures where three-dimensional effects were required. Color has also been used to highlight important statements, marginal notes, and equations. Many photographs have been added to the text.

5. A number of worked examples have been added to the text, for a total of 325. Many of the worked examples are now followed by exercises with answers, which are extensions of the worked examples.

6. As an additional motivational component, the book now contains 8 essays written by guest authors. These essays cover a wide variety of topics describing many current applications in physics, and some of the more exciting recent discoveries. The essays are optional reading for the student, but an attempt has been made to locate them in related chapters.

Objectives

The main objectives of this introductory physics textbook are twofold: to provide the student with a clear and logical presentation of the basic concepts and principles of physics, and to strengthen an understanding of the concepts and principles through a broad range of interesting applications to the real world. In order to meet these objectives, emphasis is placed on sound physical arguments. At the same time, I have attempted to motivate the student through practical examples which demonstrate the role of physics in other disciplines.

Coverage

The material covered in this book is concerned with fundamental topics in classical physics and an introduction to modern physics. The book is divided into six parts: Part I (Chapters 1–15) deals with the fundamentals of Newtonian mechanics and the physics of fluids; Part II (Chapters 16–18) covers wave motion and sound; Part III (Chapters 19–22) is concerned with heat and thermodynamics; Part IV (Chapters 23–34) deals with electricity and magnetism; Part V (Chapters 35–38) treats the properties of light and the field of geometric and wave optics; Part VI (Chapters 39–40) represents an introduction to the theory of relativity and quantum physics. This order of presentation differs from the first edition in that the chapters on wave motion and sound now precede the treatment of electricity and magnetism.

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 easily accessible and should be styled and written for ease in instruction. With these points in mind, I have included many pedagogic features in the textbook which are intended to enhance its usefulness to both the student and instructor. These are as follows:

Organization The book is divided into six parts: mechanics, wave motion and sound, heat and thermodynamics, electricity and magnetism, light and optics, and modern physics. Each part includes an overview of the subject matter to be covered in that part and some historical perspectives.

Style As an aid for rapid comprehension, I have attempted to write the book in a style that is clear, logical, and succinct. The writing style is somewhat informal and relaxed, which I hope students will find appealing and enjoyable to read. New terms are carefully defined, and I have tried to avoid jargon.

Worked Examples A large number of worked examples (325) of varying difficulty are presented as an aid in understanding concepts. In many cases, these examples will serve as models for solving the end-of-the-chapter problems. The examples are set off with colored bars for ease of location, and most examples are given titles to describe their content.

Worked Example Exercises As an added feature of this second edition, many of the worked examples are followed immediately by exercises with answers. These exercises are intended to make the textbook more interactive with the student, and to test immediately the student's understanding of problem-solving techniques. The exercises represent extensions of the worked examples and are numbered in case the instructor wishes to assign them for homework.

Problems An extensive set of problems is included at the end of each chapter, with a total of 2009 problems for the text. This represents an increase of more than 200 problems compared with the first edition. Answers to odd-numbered problems are given at the end of the book in a section which is shaded at the edges for ease of location. For the convenience of both the student and instructor, about ⅔ of the problems are keyed to specific sections of the chapter. The remaining problems, labeled "General Problems," are not keyed to specific sections. In general, the problems within a given section are presented such that the straightforward problems are first, followed by problems of increasing difficulty. I have also included a small number of challenging problems which are marked with a bullet (•). In my opinion, assignments should consist mainly of the keyed problems so as to help build self-confidence in students.

Calculator/Computer Problems Numerical problems that can be best solved with the use of programmable calculators or a computer are given in a selected number of chapters. These will be useful in those courses where the instructor wishes to put programming skills to practice.

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

Previews Most chapters begin with a chapter preview, which includes a brief discussion of chapter objectives and content.

Thought Questions A list of questions requiring verbal answers is given at the end of each chapter (644 total). Some questions 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 most questions are included in the Student Study Guide With Computer Exercises that accompanies the text.

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

Guest Essays As an added motivational feature in this second edition, I have included 8 essays written by guest authors. Most of these essays cover topics of current interest to scientists and engineers and are intended as supplemental readings for the student.

Special Topics Many chapters include special topic sections which are intended to expose the student to various practical and interesting applications of physical principles. Most of these are considered optional, and as such are labeled with an asterisk (*).

Important Statements and Equations Most important statements and definitions are set in color for added emphasis and ease of review. Important equations are shaded in color for review or reference.

Marginal Notes Comments and marginal notes set in color are used to locate important statements, equations, and concepts in the text.

Illustrations The readability and effectiveness of the text material and worked examples are enhanced by the large number of figures, diagrams, photographs, and tables. A second color is used to add clarity to the artwork. For example, vectors are color-coded, and curves in *xy*-plots are drawn in color. Three-dimensional effects are produced with the use of airbrushed areas, where appropriate.

Mathematical Level Calculus is introduced gradually, keeping in mind that a course in calculus is often taken concurrently. Most steps are shown when basic equations are developed, and reference is often made to mathematical appendices at the end of the text. Vector products are introduced later in the text where they are needed in physical applications. The dot product is introduced in Chapter 7, "Work and Energy." The cross product is introduced in Chapter 11, which deals with rotational dynamics.

Appendices and Endpapers Several appendices are provided at the end of the text. 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 review 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, and the SI units of physical quantities, as well as a periodic chart. Other useful information, including fundamental constants and physical data, mathematical symbols, the Greek alphabet, and standard abbreviation of units appears on the endpapers.

Ancillaries The ancillaries available with this text include an Instructor's Solutions Manual, a Printed Test Bank containing over 1200 multiple choice questions, a Computerized Test Bank, a Student Study Guide with Computer Exercises, a Courseware Disk Software package to accompany the Study Guide, and a set of Overhead transparencies.

The Student Study Guide With Computer Exercises is a unique student aid in that it combines the value of a problem-solving oriented study guide with a select group of integrated and interactive computer exercises. Most chapters in the study guide contain a list of objectives, skills necessary for that unit, a review and summary of important concepts, a list of equations and their meanings, answers to most end-of-chapter questions, and several programmed exercises that test the student's understanding of concepts and methods of problem solving. The Study Guide also includes the option of using a select group of computer programs (presented in special computer modules) that are interactive in nature. That is, the student's input will have direct and immediate effect on the output. This feature will enable students to work through many challenging numerical problems, and experience the power of the computer in scientific computations. The computer exercises contained in the study guide direct the student's use of the programs contained on the Courseware Disk, which is available upon adoption of the Study Guide.

Teaching Options

This book is structured in the following sequence of topics: classical mechanics, matter waves, heat and thermodynamics, electricity and magnetism, light waves, optics, relativity, and an introduction to quantum physics. This presentation is a more traditional sequence and differs from that in the first edition in that the subject of matter waves is presented before electricity and magnetism. Some instructors may prefer to cover this material after completing electricity and magnetism (after Chapter 34). Others may prefer to cover matter waves and optics before electricity and magnetism. (For this latter order, I suggest that Chapter 34 on electromagnetic waves be covered following the material on electricity and magnetism. The chapter on relativity was placed near the end of the text because this topic is often treated as an introduction to the era of "modern physics." If time permits, instructors may choose to cover Chapter 39 after completing Chapter 14, which concludes the material on newtonian mechanics.

For those instructors teaching a two-semester sequence, some sections and chapters could be deleted without any loss in continuity. I have labeled these with asterisks(*) in the Table of Contents and in the appropriate sections of the text. For student enrichment, some of these sections or chapters could be given as extra reading assignments. The guest essays could also serve the same purpose.

Acknowledgments

Both editions of this textbook were prepared with the guidance and assistance of many professors who reviewed part or all of the manuscript. I wish to acknowledge the following scholars and express my appreciation for their suggestions, criticisms, and encouragement:

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And last, I thank my wonderful family for their continued patience and understanding. The completion of this enormous task would not have been possible without their endless love and faith in me.

Raymond A. Serway
James Madison University
Harrisonburg, Virginia
March 20, 1985

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.

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, and your ability to solve the problems in the text. Ask questions whenever you feel it is necessary.

Study Schedule

It is important to set up a regular study schedule, preferably on a daily basis. Make sure to read the syllabus for the course and adhere to the schedule set by your instructor. The lectures will be much more meaningful if you read the corresponding textual material before attending the lecture. As a general rule, you should devote about two hours of study time for every hour in class. If you are having trouble with the course, seek the advice of the instructor or students who have taken the course. You may find it necessary to seek further instruction from experienced students. Very often, instructors will offer review sessions in addition to regular class periods. It is important that you avoid the practice of delaying study until a day or two before an exam. More often than not, this will lead to disastrous results. Rather than an all night study session, it is better to briefly review the basic concepts and equations, followed by a good night's rest. If you feel in need of additional help in understanding the concepts, preparing for exams, or in problem-solving, we suggest that you acquire a copy of the student study guide which accompanies the text, which should be available at your college bookstore.

Use the Features

You should make full use of the various features of the text discussed in the preface. For example, marginal notes are useful for locating and describing important equations and concepts, while important statements and definitions are highlighted in color. Many useful tables are contained in appendices, but most are incorporated in the text where they are used most often. Appendix B is a convenient review of mathematical techniques. Answers to odd-numbered problems are given at the end of the text, and answers to end-of-chapter questions are provided in the study guide. Exercises (with answers), which follow some worked examples, represent extensions of those examples, and in most cases you are expected to perform a simple calculation. Their purpose is to test your problem-solving skills as you read through the text. An overview of the entire text is given in the table of contents, while the index will enable you to locate specific material quickly. Footnotes are sometimes used to supplement the discussion or to cite other references on the subject. Many chapters include problems that require the use of programmable calculators or computers. These are intended for those courses that place some emphasis on numerical methods. You may want to develop appropriate programs for some of these problems even if they are not assigned by your instructor.

After reading a chapter, you should be able to define any new quantities introduced in that chapter, and discuss the principles and assumptions that were used to arrive at certain key relations. The chapter summaries and the review sections of the study guide should help you in this regard. In some cases, it will be necessary to refer to the index of the text to locate certain topics. You should be able to correctly associate with each physical quantity a symbol used to represent that quantity and the unit in which the quantity is specified. Furthermore, you should be able to express each important relation in a concise and accurate prose statement.

Problem Solving

R.P. Feynman, Nobel laureate in physics, once said, "You do not know anything until you have practiced." In keeping with this statement, I strongly advise that you develop the skills necessary to solve a wide range of problems. Your ability to solve problems will be one of the main tests of your knowledge of physics, and therefore you should try to solve as many problems as possible. It is essential that you understand basic concepts and principles before attempting to solve problems. It is good practice to try to find alternate solutions to the same problem. For example, problems in mechanics can be solved using Newton's laws, but very often an alternative method using energy considerations is more direct. You should not deceive yourself into thinking you understand the problem after seeing its solution in class. You must be able to solve the problem and similar problems on your own.

The method of solving problems should be carefully planned. A systematic plan is especially important when a problem involves several concepts. First, read the problem several times until you are confident you understand what is being asked. Look for any key words that will help you interpret the problem, and perhaps allow you to make certain assumptions. Your ability to interpret the question properly is an integral part of problem solving. You should acquire the habit of writing down the information given in a problem, and decide what quantities need to be found. You might want to construct a table listing quantities given, and quantities to be found. This procedure is sometimes used in the worked examples of the text. After you have decided on the method you feel is appropriate for the situation, proceed with your solution.

I often find that students fail to recognize the limitations of certain formulas or physical laws in a particular situation. It is very important that you understand and remember the assumptions which underlie a particular theory or formalism. For example, certain equations in kinematics apply only to a particle moving with constant acceleration. These equations are not valid for situations in which the acceleration is not constant, such as the motion of an object connected to a spring, or the motion of an object through a fluid.

Experiments

Physics is a science based upon experimental observations. In view of this fact, I recommend that you try to supplement the text through various types of "hands-on" experiments, either at home or in the laboratory. These can be used to test ideas and models discussed in class or in the text. For example, the common "Slinky" toy is excellent for studying traveling waves; a ball swinging on the end of a long string can be used to investigate pendulum motion; various masses attached to the end of a vertical spring or rubber band can be used to determine their elastic nature; an old pair of Polaroid sunglasses and some discarded lenses and magnifying glass are the components of various experiments in optics; you can get an approximate measure of the acceleration of gravity by dropping a ball from a known height by simply measuring the time of its fall with a stopwatch. The list is endless. When physical models are not available, be imaginative and try to develop models of your own.

Scientific Method

All that has been said can be summarized in an approach called the scientific method. The scientific method, which is used in all branches of science, consists of five steps:

1. Recognize the problem.
2. Hypothesize an answer.
3. Predict a result based upon the hypothesis.
4. Devise and perform an experiment to check the hypothesis.
5. Develop a theory which links the confirmed hypothesis to previously existing knowledge.

Someone once said that there are only two professions in which people truly enjoy what they are doing: professional sports and physics. I suspect that this is an exaggeration, but it is true that both fields are exciting and stretch your skills to the limit. It is my sincere hope that you too will find physics an exciting and enjoyable experience, and that you will profit from this experience, regardless of your chosen profession.

Welcome to the exciting world of physics.

> Whatever trouble life holds for you, that part of your lives which you spend finding out about things, things that you can tell others about, and that you can learn from them, that part will be essentially a gay, a sunny, a happy life, not untouched by rivalry, maybe not even untouched by an occasional regret that somebody else thought of something that you should have thought of first, but on the whole, one of those nobler parts of the human experience. This makes it true that the life of the scientist is, along with the life of the poet, soldier, prophet, and artist, deeply relevant to man's understanding of his situation and his view of his destiny.
>
> J. ROBERT OPPENHEIMER
> *Uncommon Sense,*
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