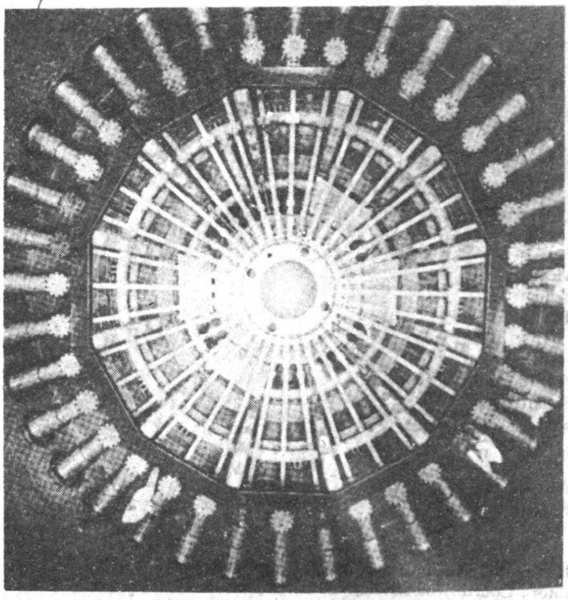
PHYSICS



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PHYSICS

For Scientists and Engineers/ with Modern Physics

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In memory of my parents, for their love and guidance during those formative years, and to my brothers and sisters for keeping and spreading the wonderful family spirit.

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Preface

This textbook is intended for a course in introductory physics for students majoring in science or engineering. The book is an extended version of *Physics: For Scientists and Engineers* in that it includes four additional chapters covering selected topics in modern physics. This material on modern physics has been added to meet the needs of those universities which choose to cover the basic concepts of quantum physics and its application to atomic, molecular, and nuclear physics as part of their curriculum.

Most of the material in this text was written over a period of several years while the author taught introductory physics courses at Clarkson College of Technology and James Madison University. During this period, most of the material was classroom-tested, and student critiques were solicited. Many of these comments were taken into consideration in the preparation of the final manuscript.

The entire contents of the text could be covered in a three-semester course, but it is possible to use the material in shorter sequences with the omission of selected chapters and sections. The mathematical background of the student taking this course should ideally include one semester of calculus. If that is not possible, the student should be enrolled in a concurrent course in introduction to calculus.

The material in this book deals with fundamental topics in classical physics and modern physics. The various parts of the book can be categorized as follows: Newtonian Mechanics (Chapters 1–14), Mechanics of Solids and Fluids (Chapter 15), Heat and Thermodynamics (Chapters 16–19), Electricity and Magnetism (Chapters 20–31), Waves and Optics (Chapters 32–39), and Modern Physics (Chapters 40–45).

My major objective in writing this text has been to provide the student with a clear and logical approach to the basic principles of classical and modern physics. Emphasis is placed on presenting the concepts and applications of physics in a precise, but realistic fashion.

It has been my experience that many students struggle through such a course for a variety of reasons such as an inadequate mathematical background. I have tried to keep such students in mind by introducing the calculus slowly. Tutorial remarks are often provided in the text and in problems involving more advanced mathematical techniques. Since many students taking such a course may have had little or no previous training in physics, I have chosen to introduce only a few concepts in each chapter. Furthermore, I have included a large number of illustrative examples which should assist the student in understanding the concepts, and could provide some basis for working out end-of-the-chapter exercises and problems.

It is my view that a textbook should be the student's major "guide" for understanding and learning the material. Furthermore, a textbook should be styled and written for ease in instruction. In order to meet these goals, the book contains the following features:

(1) Most chapters begin with a chapter preview, which includes some introductory remarks on the objectives of that unit.
(2) The text is written in an informal style, which I hope students will find appealing and enjoyable to read.
(3) Many examples of varying difficulty are presented as an aid in understanding the concepts. Many of these worked examples will serve as models for problem-solving. The examples are boxed so as to avoid confusion with the text material.
(4) Many chapters include special topic sections which are intended to expose the student to various contemporary and interesting applications of physics. These topics are closely related to the material covered in that chapter so that the student can appreciate their relevance. The special topics include motion in the presence of resistive forces, energy and the automobile, energy from the tides, rocket propulsion, energy from the wind, thermal pollution, devices such as the oscilloscope, lasers, generators, motors, semiconducting diodes and transistors, filter circuits, power transmission, optical instruments, x-ray diffraction, van Allen belts, magnetic bottles, and nuclear reactors.
(5) Two introductory chapters are included to "set the stage" for the text and to introduce some basic mathematical tools such as the use of vectors and unit vector notation.
(6) 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.
(7) Calculus is introduced gradually, keeping in mind that a course in calculus is often taken concurrently. Several mathematical appendices are included which provide reviews in algebra, geometry, trigonometry, differential calculus and integral calculus.
(8) Questions requiring verbal answers are included at the end of many sections. Some questions provide the student with a means of self-testing the contents of that particular section. Other questions could serve as a basis for classroom discussion. Answers to selected questions can be found in the Student Study Guide.
(9) An extensive set of student exercises and problems is included at the end of each chapter. (The text contains approximately 1450 exercises and 615 problems.) Most exercises are straightforward in nature and are intended to test the student's basic understanding of the material. The reader should not be misled by the terms "exercises" and "problems" since many exercises are actually intermediate level problems. For the convenience of both the student and instructor, the exercises are keyed to the various sections. The problems are generally more challenging and usually involve several concepts. Problems which are especially thought-provoking often include hints. Answers to the odd-numbered exercises and problems are given at the end of the book. In my opinion, assignments should consist of many more exercises than problems. This technique should help in building self-confidence in students.
(10) Marginal notes and comments are used to locate important statements, equations and concepts in the text. Important equations are set in a screened box for review or reference.
(11) Chapter summaries are provided to review the important concepts and relations discussed in that chapter. This feature is especially useful for the student for both problem-solving and self-study.
(12) A number of appendices are included to supplement textual information. In addition to the mathematical reviews, the appendices contain tables of conversion factors, physical data, integrals, derivatives, mathematical symbols, and the SI units of physical quantities.
(13) The international system of units (SI), sometimes called the metric system,

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_o	$6.022\ 045\ (31) \times 10^{26}$ kmol^{-1}
Bohr magneton	$\mathfrak{M}_s = \dfrac{e\hbar}{2m_e}$	$9.274\ 078\ (36) \times 10^{-24}$ A · m^2
Bohr radius	$r_o = \dfrac{\hbar^2}{m_e e^2 k}$	$0.529\ 177\ 06(44) \times 10^{-10}$ m
Boltzmann's constant	$k = R/N_o$	$1.380\ 662\ (44) \times 10^{-23}$ 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	$8.314\ 41(26) \times 10^3$ J/K · kmol
Gravitational constant	G	6.672×10^{-11} N · m^2/kg^2
Hydrogen ground state	$E_o = \dfrac{m_e e^4 k^2}{2\hbar^2} = \dfrac{e^2 k}{2r_o}$	$13.605\ 804(36)$ 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_o	$4\pi \times 10^{-7}$ N/A^2
Permittivity of free space	ε_o	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.

Physical Data Often Used

Acceleration due to gravity, at the earth's surface	9.81 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)	1.00×10^3 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

Mathematical Symbols

$=$ is equal to	$<$ is less than
$\neq$ is not equal to	$\gg$ is much greater than
$\equiv$ is defined as	$\ll$ is much less than
$\sim$ is proportional to	$\|x\|$ the absolute value of x
$>$ is greater than	$\sum$ the sum of

B1

Gauss' Probability Integral and Others

$$I_0 = \int_0^\infty e^{-\alpha x^2}\,dx = \frac{1}{2}\sqrt{\frac{\pi}{\alpha}} \qquad \text{(Gauss' probability integral)}$$

$$I_1 = \int_0^\infty x e^{-\alpha x^2}\,dx = \frac{1}{2\alpha}$$

$$I_2 = \int_0^\infty x^2 e^{-\alpha x^2}\,dx = -\frac{dI_0}{d\alpha} = \frac{1}{4}\sqrt{\frac{\pi}{\alpha^3}}$$

$$I_3 = \int_0^\infty x^3 e^{-\alpha x^2}\,dx = -\frac{dI_1}{d\alpha} = \frac{1}{2\alpha^2}$$

$$I_4 = \int_0^\infty x^4 e^{-\alpha x^2}\,dx = \frac{d^2 I_0}{d\alpha^2} = \frac{3}{8}\sqrt{\frac{\pi}{\alpha^5}}$$

$$I_5 = \int_0^\infty x^5 e^{-\alpha x^2}\,dx = \frac{d^2 I_1}{d\alpha^2} = \frac{1}{\alpha^3}$$

$$\vdots$$

$$I_{2n} = (-1)^n \frac{d^n}{d\alpha^n} I_0$$

$$I_{2n+1} = (-1)^n \frac{d^n}{d\alpha^n} I_1$$

Some Fundamental Constants

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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.

is used throughout the book. The "British engineering" system of units is used only to a limited extent in the early chapters on mechanics.
(14) The text contains a generous collection of illustrations and photographs. These are included to clarify and/or expand upon discussions and examples in the text.

As an additional instructional aid to students, a study guide is available which is designed to provide further drill on problem-solving techniques and physical concepts. Most chapters in the study guide contain a list of objectives, skills necessary for that unit, a review list of important quantities and concepts, a list of equations and their meanings, answers to selected questions from the text, and finally, several programmed exercises which test the students' understanding of concepts and methods of problem solving.

This book is structured in the following sequence of topics: classical mechanics, heat and thermodynamics, electricity and magnetism, matter waves, optics, special relativity, and modern physics. This is a slight departure from the more traditional sequence where matter waves are covered before electricity and magnetism. I have chosen to unify the treatment of waves in this manner since this order of presentation is more logical in a three-semester sequence. Some instructors may prefer to cover matter waves (Chapters 32, 33, and 34) after completing Chapter 19. Others may prefer to cover waves and optics (Chapters 32 through 39) before electricity and magnetism (Chapters 20 through 31). The material on special relativity (Chapter 40) was placed so as to serve as an introduction to the era of "modern physics." Some instructors may choose to cover special relativity after completing Chapter 14, which concludes the material on newtonian mechanics. The last five chapters are entirely devoted to topics in modern physics. Chapter 41 is an introduction to quantum physics including important early developments, basic concepts of quantum physics, and the Bohr theory of the hydrogen atom. Chapter 42 deals with wave mechanics and its application to many one-dimensional systems. Chapter 43 is concerned with the application of wave mechanics to the structure of atoms and molecules. Chapter 44 is an introduction to nuclear physics, with emphasis on nuclear structure, nuclear models, radioactivity, and nuclear reactions. Finally, Chapter 45 describes the processes of nuclear fission, nuclear fusion, and nuclear reactors associated with these processes. This chapter also includes a discussion of the interaction of radiation with matter.

For those instructors teaching a two-semester sequence, some sections and chapters could be deleted without any loss in continuity. I have labeled these in the Table of Contents with asterisks (*). For student enrichment, some of these sections or chapters could be given as reading assignments. Further details regarding optional materials and suggestions to the instructor are given in the instructor's manual.

Those of you who use this textbook might find that certain sections could be further elaborated on or clarified. Any such suggestions, new ideas or criticisms are welcomed and will be taken into consideration for future editions.

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To The Student

As I mentioned in the preface, (which I hope you have read), this book contains many features which should be of benefit to you, the student. Therefore, I feel it is appropriate to offer some words of advice which may be useful for understanding the material in the text. These comments are based upon my personal experiences in teaching this course over the last fourteen years.

Maintain a positive attitude towards the subject matter, keeping in mind that physics is the most fundamental of all natural sciences. Other science and engineering courses that follow will use the same physical principles, so it is important that you understand the various concepts, formalisms, and applications discussed in the text.

In order to obtain a thorough understanding of the concepts and principles, you should read the text carefully. Keep in mind that few people are able to absorb the full meaning of scientific writing after one reading. Several readings of the text and your lecture notes may be necessary. Your lectures and laboratory work should supplement the text and should help clarify some of the more difficult material. Memorizing equations, derivations, and definitions presented in the text or in class (in itself) does not necessarily mean you really understand the material. You will increase your level of understanding through a combination of efficient study habits, discussions with other students and instructors, and asking questions when you feel it is necessary. If you are reluctant to ask questions in class, seek private consultations. You will be surprised to find how easily concepts can be learned on a one-to-one basis.

It is important to set up a regular study schedule, preferably on a daily basis. Make sure to stick to the schedule set by your instructor. The lectures will be much more meaningful if you read the corresponding textual material in advance. A good rule of thumb to follow is at least two hours of study 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 instruction from more experienced students, and very often review sessions may be offered. In any event, you should try to avoid the practice of delaying study until a few days before an exam. This will often lead to disastrous results. If you feel in need of additional help in understanding the concepts, or in problem-solving, I suggest that you obtain the student study guide as a supplement to the text. The guide, which is keyed to the text, contains statements of chapter objectives, review lists, a review of concepts and equations, answers to selected questions from the text, worked examples, and programmed exercises. The programmed exercises are intended to serve as a self-test of the concepts and your ability to solve problems.

You should make full use of the various features of the text discussed in the preface. For example, marginal notes are useful for reviewing key concepts and definitions, while the appendices provide a review of mathematics and many useful tables. Note that answers to the odd exercises and problems are given at the back of the text. An overview of the entire text is given in the table of contents, while the index will enable you to quickly locate specific material. Footnotes are sometimes used to add notes of interest to the text, or to cite other references on the subject.

R. P. Feynman, Nobel laureate in physics, once said, "You do not know anything until you have practiced." In keeping with this statement, the most important skill you must develop from this course is the ability to solve problems. Your instructor will probably assign 8 or 10 problems per week in this course. You should try to solve as many exercises and problems as possible. Your ability to solve problems will be one of the main tests of your knowledge of physics. It is essential that you understand basic concepts and principles before attempting to solve the problems. It is good practice to try to find alternate solutions to the same problem. For example, many problems in mechanics can be solved using Newton's law of motion, but very often an alternate method using energy considerations is more direct. You should not deceive yourself into thinking you understand the problem after seeing its solution in class. If a problem involves several concepts, be sure to carefully follow a systematic plan in your solution. Always read the problem several times until you are confident you understand the question, and then note the information provided. Your ability to properly interpret the question is an integral part of problem-solving. Finally, decide on the method you feel is applicable to the problem, and proceed with your solution. If you are not successful, it would be wise to reread some portions of the text. Note that exercises are keyed to specific sections in order to simplify the process of obtaining information from the text.

Very often, students fail to recognize the limitations of certain formulas or physical laws in a particular situation. It is very important that you remember the assumptions which underlie various developments. For example, the equations of kinematics in linear motion apply only to a particle moving with constant acceleration. There are many motions for which the acceleration is not constant, such as the motion of an object attached to a spring, or the motion of an object through a resistive medium. In such cases, you must use the more general approach which involves solving the equation of motion.

Physics is a science based upon experimental observations. Therefore I recommend that you try to supplement the text through models and experiments, whenever possible. These home or laboratory experiments can be used to test ideas and models discussed in the text or in class. For example, the common "Slinky" toy is invaluable for demonstrating traveling waves; a piece of string and a ball can be used to investigate pendulum motion; an old pair of Polaroid sunglasses and some discarded lenses and magnifying glass are the components of various experiments in optics; elastic collisions can be demonstrated by studying billiard ball collisions in the pool room, with the addition of a paper-covered table to provide a permanent record of the collisions. The list is endless. When physical models are not available, try to develop "mental" models, and devise thought-provoking experiments to improve your understanding of the concepts or the situation at hand.

It is my hope that you will enjoy reading this text and profit from its content. After you have completed the course, I hope that you will have a good understanding of the ideas of physics, and its application to many real world situations.

Welcome to the exciting world of physics.

Contents Overview

° *These sections are option*

Table of Contents

° *These sections are optional.*