Physics

PART II

DAVID HALLIDAY
ROBERT RESNICK

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SELECTED PHYSICAL CONSTANTS

(See Appendix A for a more complete list)

Speed of light	c	3.00×10^8 meters/sec $= 1.86 \times 10^5$ miles/sec
Mass-energy relation	$c^2(=E/m)$	931 Mev/amu $= 8.99 \times 10^{16}$ joules/kg
Gravitational constant	G	6.67×10^{-11} nt-m^2/kg^2
Universal gas constant	R	8.31 joules/mole °K = 1.99 cal/mole °K = 0.0823 li-atm/mole °K
Triple point of water	T_{tr}	273.16 °K
Permeability constant	μ_0	1.26×10^{-6} henry/meter
Permittivity constant	ϵ_0	8.85×10^{-12} farad/meter
Avogadro's constant	N_0	6.02×10^{23} molecules/mole
Boltzmann's constant	k	1.38×10^{-23} joule/molecule °K
Planck's constant	h	6.63×10^{-34} joule-sec
Elementary charge	e	1.60×10^{-19} coul
Electron rest mass	m_e	9.11×10^{-31} kg
Electron charge-to-mass ratio	e/m_e	1.76×10^{11} coul/kg
Proton rest mass	m_p	1.67×10^{-27} kg
Electron magnetic moment	μ_e	9.27×10^{-24} joule/tesla

SELECTED PHYSICAL PROPERTIES

Density of air (STP)	1.29 kg/meter^3
Density of water (20° C)	1.00×10^3 kg/meter^3
Density of mercury (20° C)	13.5×10^3 kg/meter^3
Speed of sound in dry air (STP)	331 meters/sec = 1090 ft/sec
Acceleration of gravity (standard)	9.81 meters/sec^2 = 32.2 ft/sec^2
Standard atmosphere	1.01×10^5 nt/meter^2 = 14.7 lb/in.^{2} = 760 mm-Hg
Mean radius of the earth	6.37×10^6 meters = 3960 miles
Mean earth-sun distance	1.49×10^8 km = 92.9×10^6 miles
Mean earth-moon distance	3.80×10^5 km = 2.39×10^5 miles
Mass of earth	5.98×10^{24} kg
Heat of fusion of water (0° C, 1 atm)	79.7 cal/gm
Heat of vaporization of water (100° C, 1 atm)	539 cal/gm
Melting point of ice	0.00° C = 273.15° K
Ratio of specific heats (γ) for air (20° C)	1.40
Wavelength of the sodium yellow doublet	5892 A
Index of refraction of water (@ 5892 A)	1.33
Index of refraction of crown glass (@ 5892 A)	1.52

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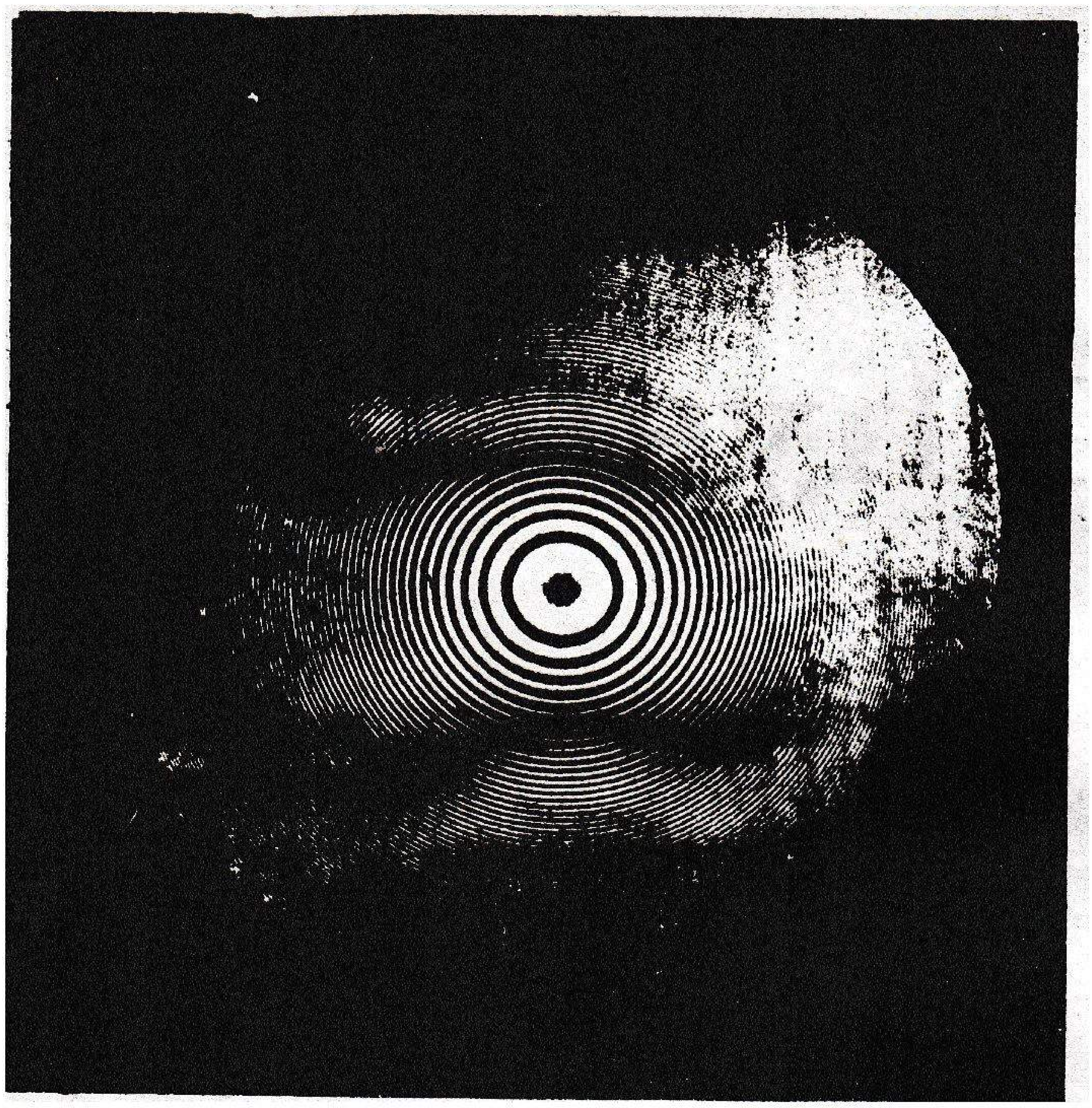

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Physics, Part II, is a revised printing of the second edition of ***Physics for** Students of Science and Engineering*. In this (1966) new printing of Part II, the following revisions have been made.

1. A supplementary set of 142 problems has been provided. These have been carefully assembled so as to permit, when combined with the numerous problems in the original set, a wider choice of area of interest and level of difficulty than heretofore available.
2. A new Topical Supplement, on the differential form of Maxwell's equations and the electromagnetic wave equation, has been written for reference of students whose instructors choose to discuss this more advanced material.
3. The original appendices have been expanded and modernized and some new ones have been added in order to increase the usefulness and accuracy of such reference material. Front and back end-papers have been changed accordingly.
4. Pagination, numbered references, symbols and units, have been changed, where necessary, for consistency with the new Part I and the above revisions of Part II.

Preface to the Second Edition

This revision of Part II of *Physics for Students of Science and Engineering*, which we hope will make our book more useful to students and instructors, is based on classroom experience at many institutions during the last two years. The basic outline of the book and its underlying philosophy remain unchanged. We have, however, modified the treatment of many topics, among them Ampère's, Faraday's, Gauss's and Lenz's laws and Huygens' principle, to make them clearer and more explicit than before. The experimental basis of the laws of physics has received increased stress, and new experimental material, such as the radiation pressure measurements of Nichols and Hull, optical masers, relativistic particle accelerators, and fiber optics illustrate the basic concepts. More than half the figures have been redrawn for greater clarity, and new figures and photographs have been inserted in key places. The questions and problems have been re-evaluated, and more than 200 are new.

In a few places we have supplied new sections either to extend or to improve the understanding of the basic material. For example, there are sections in reduced type on the electric vectors (**E**, **D**, and **P**) and on the magnetic vectors (**B**, **H**, and **M**). *RC* circuits are discussed, the Compton effect has been included in the treatment of the wave-particle duality, and a discussion of electromagnetic fields as seen by observers in relative motion has been added.

Other significant changes are (1) references to the literature available to students have been supplemented and brought up to date; (2) the sign conventions for geometrical optics have been put on a more physical basis; (3) attention has been called to examples or problems that contain important new material by using italicized titles; and (4) we have further systemized and simplified the notation in several places, particularly in wave optics.

We continue to be indebted to Dr. Benjamin Chi for assistance in preparing the illustrations and for his detailed criticism of the optics chapters. One of us (DH) wishes to thank Professor G. Wataghin for courtesies extended at the University of Turin while this revision was in progress. Finally, we extend special thanks to those students and instructors who have been kind enough to write to us about their experiences with the first edition.

David Halliday
Robert Resnick

January 1, 1962
Pittsburgh, Pennsylvania
Troy, New York

Preface to First Edition

The time lag between developments in basic science and their application to engineering practice has shrunk enormously in the past few decades. The base of engineering, once largely empirical, is now largely scientific. Today the need is to stress principles rather than specific procedures, to select areas of contemporary interest rather than of past interest, and to condition the student to the atmosphere of change he will encounter during his career. These developments require a revision of the traditional course in general physics for engineers and scientists.

The most frequent criticisms made in varying degrees of textbooks used in such a course are these: (*a*) the content is encyclopedic in that topics are not treated with sufficient depth, the discussions are largely descriptive rather than explanatory and analytical, and too many topics are surveyed; (*b*) the content is not sufficiently "modern," and applications are drawn mostly from past engineering practice rather than from contemporary physics; (*c*) the organization of the material is too compartmentalized to reveal the essential unity of physics and its principles; (*d*) the approach is highly deductive and does not stress sufficiently the connection between theory and experiment. Of course, it is unlikely that a textbook will ever be written that is not criticized on one ground or another.

In writing this textbook we have been cognizant of these criticisms and have given much thought to ways of meeting them. We have considered the possibility of reorganizing the subject matter. The adoption of an atomic approach from the beginning or a structure built around energy in its various aspects suggest themselves. We have concluded that our goals can best be achieved by modifying the selection and treatment of topics within the traditional organization. To shuffle freely the cards of subject matter content or to abandon entirely a sequence which represents the growth of physical thought invites both a failure to appreciate the Newtonian and Maxwellian syntheses of classical physics and a superficial understanding of modern physics. A solid underpinning of classical physics is essential to build the superstructure of contemporary physics in our opinion.

To illustrate how we hope to achieve our goals within this framework, we present here the principal features of our book.

1. Many topics are treated in greater depth than has been customary heretofore, and much contemporary material has been woven into the body of the text. For example, gravitation, kinetic theory, electromagnetic waves, and physical optics, among others, are treated in greater depth. Contemporary topics, such as atomic standards, collision cross section, intermolecular forces, mass-energy conversion, isotope separation, the Hall effect, the free-electron model of conductivity, nuclear stability, nuclear resonance, and neutron diffraction, are discussed where they are pertinent.

To permit this greater depth and inclusion of contemporary material, we have omitted entirely or treated only indirectly much traditional material, such as simple machines, surface tension, viscosity, calorimetry, change of state, humidity, pumps, practical engines, musical scales, architectural acoustics, electrochemistry, thermoelectricity, motors, alternating-current circuits, electronics, lens aberrations, color, photometry, and others.

2. We have tried to reveal the unity of physics in many ways. Throughout the book we stress the general nature of key ideas common to all areas of physics. For example, the conservation laws of energy, linear momentum, angular momentum, and charge are used repeatedly. Wave concepts and properties of vibrating systems, such as resonance, are used in mechanics, sound, electromagnetism, optics, atomic physics, and nuclear physics. The field concept is applied to gravitation, fluid flow, electromagnetism, and nuclear physics.

The interrelation of the various disciplines of physics is emphasized by the use of physical and mathematical analogies and by similarity of method. For example, the correspondences between the mass-spring system and the *LC* circuit or between the acoustic tube and the electromagnetic cavity are emphasized, and the interweaving of microscopic and macroscopic approaches is noted in heat phenomena and electrical and magnetic phenomena. We have tried to make a smooth transition between particle mechanics and kinetic theory, stressing that, in their classical aspects, both belong to the Newtonian synthesis. We have also sought a smooth transition between electromagnetism and wave optics, pointing frequently to the Maxwellian synthesis.

We discuss the limitations of classical ideas and the domain of their validity, and we emphasize the generalizing nature of contemporary ideas applicable in a broader domain. Throughout we aim to show the relation of theory to experiment and to develop an awareness of the nature and uses of theory.

3. Our approach to quantum physics is not the traditional descriptive one. Rather we seek to develop the contemporary concepts fairly rigorously, at a length and depth appropriate to an introductory course. In the early chapters we pave the way by pointing to the limitations of classical theory, by stressing the aspects of classical physics that bear on contemporary physics, and by choosing illustrative examples that have a modern flavor. Thus we stress fields rather than circuits, particles rather than extended bodies, and wave optics rather than geometrical optics. Among the illustrative examples are molecular potential energy curves, binding energy of a deuteron, nuclear collisions, the nuclear model of the atom, the Thomson atom model, molecular dipoles, drift speed of electrons, stability of betatron orbits, nuclear magnetic resonance, the red shift, and others too numerous to mention.

The point of view is that of developing the fundamental ideas of quantum physics. The customary descriptive chapter on nuclear physics is, for example, not present. Instead, the wave-particle duality, the uncertainty principle, the complementarity principle, and the correspondence principle are stressed.

4. The mathematical level of our book assumes a concurrent course in calculus. The derivative is introduced in Chapter 3 and the integral in Chapter 7. The related physical concepts of slope and area under a curve are developed steadily. Calculus is used freely in the latter half of the book. Simple differential equations are not avoided, although no formal procedures are needed or given for solving them. Vector notation and vector algebra, including scalar and vector products, are used throughout. Displacement is taken as the prototype vector, and the idea of invariance of vector relations is developed.

5. The number of problems is unusually large, but few are "plug-in" problems. Many involve extensions of the text material, contemporary applications, or derivations. The questions at the end of each chapter are intended to be thought-provoking; they may serve as the basis for class discussion, for essay papers, or for self-study. Only rarely can the questions be answered by direct quotation from the text.

6. The book contains an unusually large number of worked-out examples, with the "plug-in" variety used only to emphasize a numerical magnitude. Algebraic, rather than numerical, solutions are stressed. Examples sometimes extend the text treatment or discuss the fine points, but usually they are applications of the principles, often of contemporary physics.

7. The textbook has been designed to fit physics courses of various lengths. In small print there is a great deal of supplementary material of an advanced, historical, or philosophical character, to be omitted or included to varying degrees depending on interest and course length. In addition, many chapters may be regarded as optional. Each teacher will make his own choice. At our institutions Chapter 14 (statics of rigid bodies) and Chapters 41 and 42 (geometrical optics) are omitted. Other possibilities suggested, depending on emphasis or depth desired, or the nature of succeeding courses, are Chapter 12 (rotational dynamics), Chapters 17 and 18 (fluids), Chapter 24 (kinetic theory—II), Chapter 32 (emf and circuits), Chapter 46 (polarization), and Chapters 47 and 48 (quantum physics).

8. We have adopted the mks system of units throughout, although the British engineering system is also used in mechanics. Having observed the gradual exclusion, year by year, of the cgs system from advanced textbooks, we have seen fit to limit ourselves to the bare definition of the basic cgs quantities. An extensive list of conversion factors appears in Appendix G.

We wish to thank the engineering and science students at both Rensselaer Polytechnic Institute and the University of Pittsburgh who have borne with us through two successive preliminary editions. Constructive criticisms from our colleagues at each institution and from some eight reviewers have resulted in many changes. Benjamin Chi of R.P.I. has been of major service in all aspects of the preparation of the manuscript. Finally, we express our deep appreciation to our wives, not only for aid in typing and proofreading but for the patience and encouragement without which this book might never have been written.

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January 1960
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