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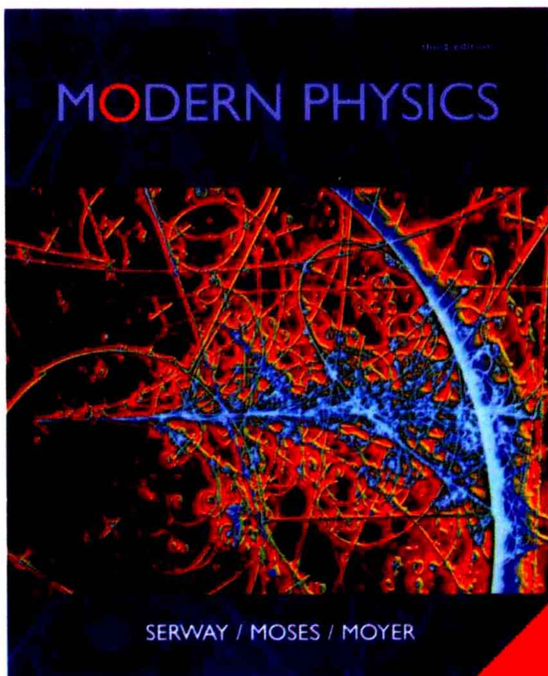
Raymond A. Serway, Clement J. Moses, Curt A. Moyer

近代物理学

（第3版）



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近代物理学

（第3版）

Modern Physics

(Third Edition)

Raymond A. Serway
Clement J. Moses
Curt A. Moyer

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Raymond A. Serway, Clement J.Moses, Curt A. Moyer

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Modern Physics（第 3 版）

影 印 版 序

本书是为修完基于微积分的物理课程的理工科学生编写的近代物理学教材。全书共分 16 章，包括两部分内容：从第 1 章到第 10 章主要是讲述相对论、量子理论和统计物理学理论；从第 11 章到第 16 章主要是介绍量子理论在分子、固体、原子核及粒子物理方面的一些基本应用，其中第 16 章（宇宙论）的内容上载在本书配套的网站上。因此，本书覆盖了在科学和技术中广泛应用的近代物理学方面的基本内容。

在讲法上，本书避免复杂的数学推导，突出物理本质和物理图像，使用了大量的图表，简单明了地阐述了近代物理学中的基本概念和基本规律。书中对教学内容的难点和疑点，均作了深入浅出的剖析，并配备了足够数量的具有针对性的例题。书中注重介绍近代物理学知识的现代应用，回答了近代物理学中的一些基本问题，例如：是什么让分子结合在一起？电子是如何穿透势垒的？固体中的电子是怎样运动的？超导体中的电流为什么能维持无限大？

本书通过引入 20 世纪物理学发展的一些重要历史资料，包括著名科学家的照片及其原创性成果介绍，还有一些实验装置的照片，增强了物理学理论的真实感和生动感。

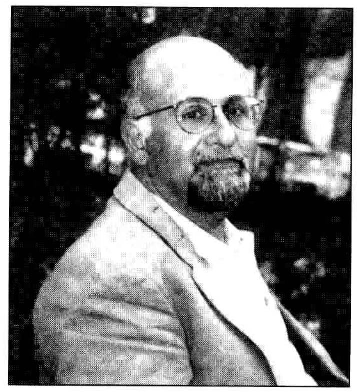
近几年来，国内一些院校的理科专业把原来普通物理课程中的原子物理学扩展为近代物理学，一些工科专业在修完大学物理课程之后也设置了近代物理学方面的课程。对于上述课程，本书都是一本很好的教材。书中的第 1 章（相对论 I）、第 2 章（相对论 II）和第 10 章（统计物理学）中的经典统计部分，在普通物理或大学物理的力学和热学中都已经讲过，这些章节可以不讲。书中还有一些内容可以让学生自学，然后组织学生进行讨论。

对于正在学习大学物理的工科学生和讲授大学物理的教师，本书也有很好的参考价值。

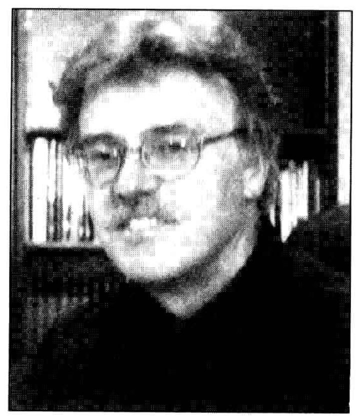
陈信义
清华大学物理系
2008 年 11 月

About the Authors

Raymond A. Serway received his doctorate at Illinois Institute of Technology and is Professor Emeritus at James Madison University. Dr. Serway began his teaching career at Clarkson University, where he conducted research and taught from 1967 to 1980. His second academic appointment was at James Madison University as Professor of Physics and Head of the Physics Department from 1980 to 1986. He remained at James Madison University until his retirement in 1997. He was the recipient of the Madison Scholar Award at James Madison University in 1990, the Distinguished Teaching Award at Clarkson University in 1977, and the Alumni Achievement Award from Utica College in 1985. As Guest Scientist at the IBM Research Laboratory in Zurich, Switzerland, he worked with K. Alex Müller, 1987 Nobel Prize recipient. Dr. Serway also held research appointments at Rome Air Development center from 1961 to 1963, at IIT Research Institute from 1963 to 1967, and as a visiting scientist at Argonne National Laboratory, where he collaborated with his mentor and friend, Sam Marshall. In addition to earlier editions of this textbook, Dr. Serway is the co-author of *Physics for Scientists and Engineers,* 6th edition, *Principles of Physics,* 3rd edition, *College Physics,* 6th edition, and the high-school textbook *Physics,* published by Holt, Rinehart, and Winston. In addition, Dr. Serway has published more than 40 research papers in the field of condensed matter physics and has given more than 60 presentations at professional meetings. Dr. Serway and his wife Elizabeth enjoy traveling, golfing, fishing, and spending quality time with their four children and seven grandchildren.



Clement J. Moses is Emeritus Professor of Physics at Utica College. He was born and brought up in Utica, New York, and holds an A.B. from Hamilton College, an M.S. from Cornell University, and a Ph.D. from State University of New York at Binghamton. He has over 30 years of science writing and teaching experience at the college level, and is a co-author of *College Physics,* 6th edition, with Serway and Faughn. His research work, both in industrial and university settings, has dealt with defects in solids, solar cells, and the dynamics of atoms at surfaces. In addition to science writing, Dr. Moses enjoys reading novels, gardening, cooking, singing, and going to operas.



Curt A. Moyer has been Professor and Chair of the Department of Physics and Physical Oceanography at the University of North Carolina-Wilmington since 1999. Before his appointment to UNC-Wilmington, he taught in the Physics Department at Clarkson University from 1974 to 1999. Dr. Moyer earned a B.S. from Lehigh University and a Ph.D. from the State University of New York at Stony Brook. He has published more than 45 research articles in the fields of condensed matter physics and surface science. In addition to being an experienced teacher, Dr. Moyer is an advocate for the uses of computers in education and developed the Web-based *QMTools* software that accompanies this text. He and his wife, V. Sue, enjoy traveling and the special times they spend with their four children and three grandchildren.

Preface

This book is intended as a modern physics text for science majors and engineering students who have already completed an introductory calculus-based physics course. The contents of this text may be subdivided into two broad categories: an introduction to the theories of relativity, quantum and statistical physics (Chapters 1 through 10) and applications of elementary quantum theory to molecular, solid-state, nuclear, and particle physics (Chapters 11 through 16).

OBJECTIVES

Our basic objectives in this book are threefold:

1. To provide simple, clear, and mathematically uncomplicated explanations of physical concepts and theories of modern physics.
2. To clarify and show support for these theories through a broad range of current applications and examples. In this regard, we have attempted to answer questions such as: What holds molecules together? How do electrons tunnel through barriers? How do electrons move through solids? How can currents persist indefinitely in superconductors?
3. To enliven and humanize the text with brief sketches of the historical development of 20th century physics, including anecdotes and quotations from the key figures as well as interesting photographs of noted scientists and original apparatus.

COVERAGE

Topics. The material covered in this book is concerned with fundamental topics in modern physics with extensive applications in science and engineering. Chapters 1 and 2 present an introduction to the special theory of relativity. Chapter 2 also contains an introduction to general relativity. Chapters 3 through 5 present an historical and conceptual introduction to early developments in quantum theory, including a discussion of key experiments that show the quantum aspects of nature. Chapters 6 through 9 are an introduction to the real "nuts and bolts" of quantum mechanics, covering the Schrödinger equation, tunneling phenomena, the hydrogen atom, and multielectron atoms, while Chapter 10 contains an introduction to statistical physics. The remainder of the book consists mainly of applications of the theory set forth in earlier chapters to more specialized areas of modern physics. In particular, Chapter 11 discusses the physics of molecules, while Chapter 12 is an introduction to the physics of solids and electronic devices. Chapters 13 and 14 cover nuclear physics, methods of obtaining energy from nuclear reactions, and medical and other applications of nuclear processes. Chapter 15 treats elementary particle physics, and Chapter 16 (available online at **http://info.brookscole.com/mp3e)** covers cosmology.

CHANGES TO THE THIRD EDITION

The third edition contains two major changes from the second edition: *First,* this edition has been extensively rewritten in order to clarify difficult concepts, aid understanding, and bring the text up to date with rapidly developing technical applications of quantum physics. Artwork and the order of presentation of certain topics have been revised to help in this process. (Many new photos of physicists have been added to the text, and a new collection of color photographs of modern physics phenomena is also available on the Book Companion Web Site.) Typically, each chapter contains new worked examples and five new end-of-chapter questions and problems. Finally, the *Suggestions for Further Reading* have been revised as needed.

Second, this edition refers the reader to a new, online (platform independent) simulation package, *QMTools,* developed by one of the authors, Curt Moyer. We think these simulations clarify, enliven, and complement the analytical solutions presented in the text. Icons in the text highlight the problems designed for use with this software, which provides modeling tools to help students visualize abstract concepts. All instructions about the general use of the software as well as specific instructions for each problem are contained on the Book Companion Web Site, thereby minimizing interruptions to the logical flow of the text. The Book Companion Web Site at **http://info.brookscole.mp3e** also contains appendices and much supplemental information on current physics research and applications, allowing interested readers to dig deeper into many topics.

Specific changes by chapter in this third edition are as follows:

- Chapter 1 in the previous editions, "Relativity," has been extensively revised and divided into two chapters. The new **Chapter 1,** entitled "Relativity I," contains the history of relativity, new derivations of the Lorentz coordinate and velocity transformations, and a new section on spacetime and causality.
- **Chapter 2,** entitled "Relativity II," covers relativistic dynamics and energy and includes new material on general relativity, gravitational radiation, and the applications GPS (Global Positioning System) and LIGO (the Laser Interferometer Gravitational-wave Observatory).
- **Chapter 3** has been streamlined with a more concise treatment of the Rayleigh-Jeans and Planck blackbody laws. Material necessary for a complete derivation of these results has been placed on our Book Companion Web Site.
- **Chapter 5** contains a new section on the invention and principles of operation of transmission and scanning electron microscopes.

- **Chapter 6,** "Quantum Mechanics in One Dimension," features a new application on the principles of operation and utility of CCDs (Charge-Coupled Devices).
- **Chapter 8,** "Quantum Mechanics in Three Dimensions," includes a new discussion on the production and spectroscopic study of anti-hydrogen, a study which has important consequences for several fundamental physical questions.
- **Chapter 10** presents new material on the connection of wavefunction symmetry to the Bose-Einstein condensation and the Pauli exclusion principle, as well as describing potential applications of Bose-Einstein condensates.
- **Chapter 11** contains new material explaining Raman scattering, fluorescence, and phosphorescence, as well as giving applications of these processes to pollution detection and biomedical research. This chapter has also been streamlined with the discussion of overlap integrals being moved to the Book Companion Web Site.
- **Chapter 12** has been carefully revised for clarification and features new material on semiconductor devices, in particular MOSFETs and chips. In addition, the most important facts about superconductivity have been summarized, updated, and included in Chapter 12. For those desiring more material on superconductivity, the entire superconductivity chapter from previous editions is available at the Book Companion Web Site along with essays on the history of the laser and solar cells.
- **Chapter 13** contains new material on MRI (Magnetic Resonance Imaging) and an interesting history of the determination of the age of the Earth.
- **Chapter 14** presents updated sections on fission reactor safety and waste disposal, fusion reactor results, and applications of nuclear physics to tracing, neutron activation analysis, radiation therapy, and other areas.
- **Chapter 15** has been extensively rewritten in an attempt to convey the thrust toward unification in particle physics. By way of achieving this goal, new discussions of positrons, neutrino mass and oscillation, conservation laws, and grand unified theories, including supersymmetry and string theory, have been introduced.
- **Chapter 16** is a new chapter devoted exclusively to the exciting topic of the origin and evolution of the universe. Topics covered include the discovery of the expanding universe, primordial radiation, inflation, the future evolution of the universe, dark matter, dark energy, and the accelerating expansion of the universe. This cosmology chapter is available on our Book Companion Web Site.

FEATURES OF THIS TEXT

QMTools Five chapters contain several new problems requiring the use of our simulation software, *QMTools*. *QMTools* is a sophisticated interactive learning tool with considerable flexibility and scope. Using *QMTools*, students can compose matter-wave packets and study their time evolution, find stationary state energies and wavefunctions, and determine the probability for particle transmission and reflection from nearly any potential well or barrier. Access to *QMTools* is available online at **http://info.brookscole.com/mp3e**.

Style. We have attempted to write this book in a style that is clear and succinct yet somewhat informal, in the hope that readers will find the text appealing and enjoyable to read. All new terms have been carefully defined, and we have tried to avoid jargon.

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

Exercises Following Examples. As an added feature, 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 key concepts and 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 and Questions. An extensive set of questions and problems is included at the end of each chapter. Most of the problems are listed by section topic. Answers to all odd-numbered problems are given at the end of the book. Problems span a range of difficulty and more challenging problems have colored numbers. Most of the questions serve to test the student's understanding of the concepts presented in a given chapter, and many can be used to motivate classroom discussions.

Units. The international system of units (SI) is used throughout the text. Occasionally, where common usage dictates, other units are used (such as the angstrom, Å, and cm^{-1}, commonly used by spectroscopists), but all such units are carefully defined in terms of SI units.

Chapter Format. Each chapter begins with a **preview,** which includes a brief discussion of chapter objectives and content. **Marginal notes** set in color are used to locate important concepts and equations in the text. Important statements are *italicized* or **highlighted,** and important equations are set in a colored box for added emphasis and ease of review. Each chapter concludes with a **summary,** which reviews the important concepts and equations discussed in that chapter.

In addition, many chapters contain **special topic sections** which are clearly marked **optional.** These sections expose the student to slightly more advanced material either in the form of current interesting discoveries or as fuller developments of concepts or calculations discussed in that chapter. Many of these special topic sections will be of particular interest to certain student groups such as chemistry majors, electrical engineers, and physics majors.

Guest Essays. Another feature of this text is the inclusion of interesting material in the form of essays by guest authors. These essays cover a wide range of topics and are intended to convey an insider's view of exciting current developments in modern physics. Furthermore, the essay topics present extensions and/or applications of the material discussed in specific chapters. Some of the essay topics covered are recent developments in general relativity, the scanning tunneling microscope, superconducting devices, the history of the laser, laser cooling of atoms, solar cells, and how the top quark was detected. The guest essays are either included in the text or referenced as being on our Web site at appropriate points in the text.

Mathematical Level. Students using this text should have completed a comprehensive one-year calculus course, as calculus is used throughout the text. However, we have made an attempt to keep physical ideas foremost so as not to obscure our presentations with overly elegant mathematics. Most steps are shown when basic equations are developed, but exceptionally long and detailed proofs which interrupt the flow of physical arguments have been placed in appendices.

Appendices and Endpapers. The appendices in this text serve several purposes. Lengthy derivations of important results needed in physical discussions have been placed on our Web site to avoid interrupting the main flow of arguments. Other appendices needed for quick reference are located at the end of the book. These contain physical constants, a table of atomic masses, and a list of Nobel prize winners. The endpapers inside the front cover of the book contain important physical constants and standard abbreviations of units used in the book, and conversion factors for quick reference, while a periodic table is included in the rear cover endpapers.

Ancillaries. The ancillaries available with this text include a Student Solutions Manual, which has solutions to all odd-numbered problems in the book, an Instructor's Solutions Manual, consisting of solutions to all problems in the text, and a Multimedia Manager, a CD-ROM lecture tool that contains digital versions of all art and selected photographs in the text.

TEACHING OPTIONS

As noted earlier, the text may be subdivided into two basic parts: Chapters 1 through 10, which contain an introduction to relativity, quantum physics, and statistical physics, and Chapters 11 through 16, which treat applications to molecules, the solid state, nuclear physics, elementary particles, and cosmology. It is suggested that the first part of the book be covered sequentially. However, the relativity chapters may actually be covered at any time because $E^2 = p^2c^2 + m^2c^4$ is the only formula from these chapters which is essential for subsequent chapters. Chapters 11 through 16 are independent of one another and can be covered in any order with one exception: Chapter 14, "Nuclear Physics Applications," should follow Chapter 13, "Nuclear Structure."

A traditional sophomore or junior level modern physics course for science, mathematics, and engineering students should cover most of Chapters 1 through 10 and several of the remaining chapters, depending on the student major. For example, an audience consisting mainly of electrical engineering students might cover most of Chapters 1 through 10 with particular emphasis on tunneling and tunneling devices in Chapter 7, the Fermi-Dirac distribution in Chapter 10, semiconductors in Chapter 12, and radiation detectors in Chapter 14. Chemistry and chemical engineering majors could cover most of Chapters 1 through 10 with special emphasis on atoms in Chapter 9, classical and quantum statistics in Chapter 10, and molecular bonding and spectroscopy in Chapter 11. Mathematics and physics majors should pay special attention to the unique development of operator methods and the concept of sharp and fuzzy observables introduced in Chapter 6. The deep connection of sharp observables with classically conserved quantities and the powerful role of sharp observables in shaping the form of system wavefunctions is developed more fully in Chapter 8.

Our experience has shown that there is more material contained in this book than can be covered in a standard one semester three-credit-hour course. For this reason, one has to "pick-and-choose" from topics in the second part of the book as noted earlier. However, the text can also be used in a two-semester sequence with some supplemental material, such as one of many monographs on relativity, and/or selected readings in the areas of solid state, nuclear, and elementary particle physics. Some selected readings are suggested at the end of each chapter.

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We wish to thank the users and reviewers of the first and second editions who generously shared with us their comments and criticisms. In preparing this third edition we owe a special debt of gratitude to the following reviewers:

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Finally, we thank all of our families for their patience and continual support.

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December 2003

Some Fundamental Constants*

QUANTITY	SYMBOL	VALUE
Atomic mass unit	u	1.6605×10^{-27} kg $931.49\ \text{MeV}/c^2$
Avogadro's number	N_A	6.022×10^{23} particles/mole
Bohr magneton	$\mu_B = \dfrac{e\hbar}{2m_e}$	9.274×10^{-24} J/T 5.788×10^{-5} eV/T
Bohr radius	$a_0 = \dfrac{\hbar^2}{m_e e^2 k}$	0.5292×10^{-10} m
Boltzmann's constant	k_B	1.381×10^{-23} J/K 8.617×10^{-5} eV/K
Coulomb constant	$k = 1/(4\pi\epsilon_0)$	$8.988 \times 10^9\ \text{N}\cdot\text{m}^2/\text{C}^2$
Electron charge	e	1.602×10^{-19} C
Electron mass	m_e	9.109×10^{-31} kg 5.486×10^{-4} u $0.5110\ \text{MeV}/c^2$
Gravitational constant	G	$6.673 \times 10^{-11}\ \text{N}\cdot\text{m}^2/\text{kg}^2$
Hydrogen ground state energy	$E_0 = -\dfrac{m_e e^4 k^2}{2\hbar^2}$	-13.61 eV
Neutron mass	m_n	1.675×10^{-27} kg 1.009 u $939.6\ \text{MeV}/c^2$
Nuclear magneton	$\mu_n = \dfrac{e\hbar}{2m_p}$	5.051×10^{-27} J/T 3.152×10^{-8} eV/T
Permeability of free space	μ_0	$4\pi \times 10^{-7}\ \text{N/A}^2$
Permittivity of free space	ϵ_0	$8.854 \times 10^{-12}\ \text{C}^2/\text{N}\cdot\text{m}^2$
Planck's constant	h	$6.626 \times 10^{-34}\ \text{J}\cdot\text{s}$ $4.136 \times 10^{-15}\ \text{eV}\cdot\text{s}$
	$\hbar = h/2\pi$	$1.055 \times 10^{-34}\ \text{J}\cdot\text{s}$ $6.582 \times 10^{-16}\ \text{eV}\cdot\text{s}$
Proton mass	m_p	1.673×10^{-27} kg 1.007 u $938.3\ \text{MeV}/c^2$
Rydberg constant	$R = \dfrac{m_e k^2 e^4}{4\pi c\hbar^3}$	$1.097 \times 10^7\ \text{m}^{-1}$
Speed of light in vacuum	c	2.998×10^8 m/s
Stefan-Boltzmann constant	σ	$5.6705 \times 10^{-8}\ \text{W/m}^2\text{K}^4$

* More precise values of physical constants are provided in Appendix A.

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