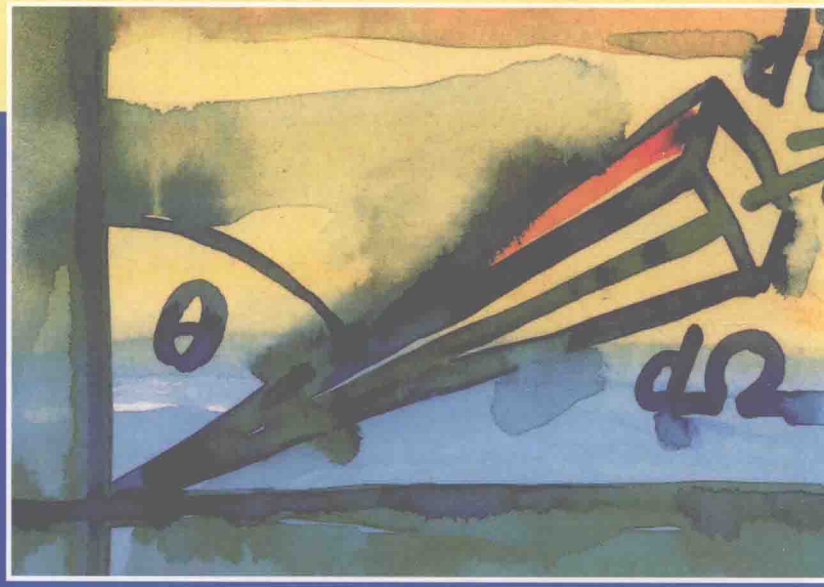
Theoretical Physics-Text & Exercise Books

Springer



Greiner

QUANTUM MECHANICS

An Introduction

Fourth Edition

量子力学导论

第 4 版（影印版）

世界图书出版公司
www.wpcbj.com.cn

需要全本请访问 www.ertongbook.com

郑 重 声 明

世界图书出版有限公司北京分公司购权英文图书仅限在中国大陆销售，不得以任何方式销往中国大陆以外地区，一旦发现违规者，我公司将追究其法律责任，追偿其违规行为给本公司及合作方造成的经济损失。

上架建议：物理学 / 英文版

ISBN 978-7-5192-5531-2

9 787519 255312 >

定价：169.00 元

www.wpcbj.com.cn

Walter Greiner

QUANTUM MECHANICS

An Introduction

With a Foreword by
D. A. Bromley

Fourth Edition
With 57 Figures
and 88 Worked Examples and Problems



Springer

图书在版编目（CIP）数据

量子力学导论 = Quantum Mechanics: An Introduction 4th ed.：第 4 版：英文 /（德）W. 格雷钠（Walter Greiner）著 . —影印本 . —北京：世界图书出版有限公司北京分公司，2018.12

ISBN 978-7-5192-5531-2

Ⅰ .①量… Ⅱ .① W… Ⅲ .①量子力学—高等学校—教材—英文 Ⅳ .① O413.1

中国版本图书馆 CIP 数据核字 (2019) 第 002465 号

0413.1

2616-Y

中文书名　量子力学导论（第 4 版）
英文书名　Quantum Mechanics: An Introduction *Fourth Edition*
著　　者　Walter Greiner
责任编辑　刘　慧　高　蓉

出版发行　世界图书出版有限公司北京分公司
地　　址　北京市东城区朝内大街 137 号
邮　　编　100010
电　　话　010-64038355（发行）　64033507（总编室）
网　　址　http://www.wpcbj.com.cn
邮　　箱　wpcbjst@vip.163.com
销　　售　新华书店
印　　刷　北京建宏印刷有限公司
开　　本　787 mm × 1092 mm　1/16
印　　张　31.75
字　　数　610 千字
版　　次　2019 年 3 月第 1 版
印　　次　2019 年 3 月第 1 次印
版权登记　01-2018-9168
国际书号　ISBN 978-7-5192-55
定　　价　169.00 元

片

（如发现印装质量问题，

Professor Dr. Walter Greiner

Institut für Theoretische Physik der
Johann Wolfgang Goethe-Universität Frankfurt
Postfach 11 19 32
60054 Frankfurt am Man
Germany

Street address:

Robert-Mayer-Strasse 8–10
60325 Frankfurt am Main
Germany

Library of Congress Cataloging-in-Publication Data applied for.

Die Deutsche Bibliothek – CIP-Einheitsaufnahme

Quantum mechanics / Walter Greiner; Berndt Müller. With a foreword by D. A. Bromley. – Berlin; Heidelberg; New York; Barcelona; Hong Kong; London; Milan; Paris; Singapore; Tokyo: Springer (Theoretical physics; ...)
Einheitssacht.: Quantenmechanik <engl.>
An introduction: with 88 worked examples and problems / with a foreword by D. A. Bromley. – 4. ed. – 2000
(Theoretical physics; Vol. 1) (Physics and astronomy online library) ISBN 978-3-540-67458-0

ISBN 978-3-540-67458-0 ISBN 978-3-642-56826-8 (eBook)
DOI 10.1007/978-3-642-56826-8

This work is subject to copyright. All rights are reserved, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilm or in any other way, and storage in data banks. Duplication of this publication or parts thereof is permitted only under the provisions of the German Copyright Law of September 9, 1965, in its current version, and permission for use must always be obtained from Springer-Verlag. Violations are liable for prosecution under the German Copyright Law.

© Springer-Verlag Berlin Heidelberg 1989, 1993, 1994, 2001
Originally published by Springer-Verlag Berlin Heidelberg New York in 2001

The use of general descriptive names, registered names, trademarks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

First published in English under the title
Quantum Mechanics: An Introduction 4th ed.
by Walter Greiner
Copyright © Springer –Verlag Berlin Heidelberg 2001
This edition has been reprinted and published under licence from
Springer Science+Business Media, LLC, part of Springer Nature.
For copyright reasons this edition is not for sale outside of China Mainland.

需要全本请访问 www.ertongbook.com

W. Greiner

QUANTUM MECHANICS

An Introduction

Springer-Verlag Berlin Heidelberg GmbH

Greiner
Quantum Mechanics
An Introduction 4th Edition

Greiner
Quantum Mechanics
Special Chapters

Greiner · Müller
Quantum Mechanics
Symmetries 2nd Edition

Greiner
Relativistic Quantum Mechanics
Wave Equations 3rd Edition

Greiner · Reinhardt
Field Quantization

Greiner · Reinhardt
Quantum Electrodynamics
2nd Edition

Greiner · Schramm · Stein
Quantum Chromodynamics
2nd Edition

Greiner · Maruhn
Nuclear Models

Greiner · Müller
Gauge Theory of Weak Interactions
3rd Edition

Greiner
Mechanics I
(in preparation)

Greiner
Mechanics II
(in preparation)

Greiner
Classical Electrodynamics

Greiner · Neise · Stöcker
Thermodynamics
and Statistical Mechanics

Foreword to Earlier Series Editions

More than a generation of German-speaking students around the world have worked their way to an understanding and appreciation of the power and beauty of modern theoretical physics – with mathematics, the most fundamental of sciences – using Walter Greiner's textbooks as their guide.

The idea of developing a coherent, complete presentation of an entire field of science in a series of closely related textbooks is not a new one. Many older physicists remember with real pleasure their sense of adventure and discovery as they worked their ways through the classic series by Sommerfeld, by Planck and by Landau and Lifshitz. From the students' viewpoint, there are a great many obvious advantages to be gained through use of consistent notation, logical ordering of topics and coherence of presentation; beyond this, the complete coverage of the science provides a unique opportunity for the author to convey his personal enthusiasm and love for his subject.

The present five volume set, *Theoretical Physics*, is in fact only that part of the complete set of textbooks developed by Greiner and his students that presents the quantum theory. I have long urged him to make the remaining volumes on classical mechanics and dynamics, on electromagnetism, on nuclear and particle physics, and on special topics available to an English-speaking audience as well, and we can hope for these companion volumes covering all of theoretical physics some time in the future.

What makes Greiner's volumes of particular value to the student and professor alike is their completeness. Greiner avoids the all too common "it follows that . . . " which conceals several pages of mathematical manipulation and confounds the student. He does not hesitate to include experimental data to illuminate or illustrate a theoretical point and these data, like the theoretical content, have been kept up to date and topical through frequent revision and expansion of the lecture notes upon which these volumes are based.

Moreover, Greiner greatly increases the value of his presentation by including something like one hundred completely worked examples in each volume. Nothing is of greater importance to the student than seeing, in detail, how the theoretical concepts and tools under study are applied to actual problems of interest to a working physicist. And, finally, Greiner adds brief biographical sketches to each chapter covering the people responsible for the development of the theoretical ideas and/or the experimental data presented. It was Auguste Comte (1798–1857) in his *Positive Philosophy* who noted, "To understand a science it is necessary to know its history". This is all too often forgotten in modern

physics teaching and the bridges that Greiner builds to the pioneering figures of our science upon whose work we build are welcome ones.

Greiner's lectures, which underlie these volumes, are internationally noted for their clarity, their completeness and for the effort that he has devoted to making physics an integral whole; his enthusiasm for his science is contagious and shines through almost every page.

These volumes represent only a part of a unique and Herculean effort to make all of theoretical physics accessible to the interested student. Beyond that, they are of enormous value to the professional physicist and to all others working with quantum phenomena. Again and again the reader will find that, after dipping into a particular volume to review a specific topic, he will end up browsing, caught up by often fascinating new insights and developments with which he had not previously been familiar.

Having used a number of Greiner's volumes in their original German in my teaching and research at Yale, I welcome these new and revised English translations and would recommend them enthusiastically to anyone searching for a coherent overview of physics.

Yale University
New Haven, CT, USA
1989

D. Allan Bromley
Henry Ford II Professor of Physics

Preface to the Fourth Edition

We are pleased once again that the need has arisen to produce a new edition of *Quantum Mechanics: Introduction*. We have taken this opportunity to make several amendments and improvements to the text. A number of misprints and minor errors have been corrected and explanatory remarks have been given at various places. Also, several new examples and exercises have been added.

We thank several colleagues and students for helpful comments, particularly Dr. Stefan Hofmann who supervised the preparation of this fourth edition of the book. Finallly, we acknowledge the agreeable collaboration with Dr. H. J. Kölsch and his team at Springer-Verlag, Heidelberg.

Frankfurt am Main
July 2000

Walter Greiner

Preface to the Third Edition

The text *Quantum Mechanics – An Introduction* has found many friends among physics students and researchers so that the need for a third edition has arisen. There was no need for a major revision of the text but I have taken the opportunity to make several amendments and improvements. A number of misprints and minor errors have been corrected and a few clarifying remarks have been added at various places. A few figures have been added or revised, in particular the three-dimensional density plots in Chap. 9.

I am grateful to several colleagues for helpful comments, in particular to Prof. R.A. King (Calgary) who supplied a comprehensive list of corrections. I also thank Dr. A. Scherdin for help with the figures and Dr. R. Mattiello who has supervised the preparation of the third edition of the book. Furthermore I acknowledge the agreeable collaboration with Dr. H. J. Kölsch and his team at Springer-Verlag, Heidelberg.

Frankfurt am Main
July 1994

Walter Greiner

需要全本请访问 www.ertongbook.com

Preface to the Second Edition

Like its German companion, the English edition of our textbook series has also found many friends, so that it has become necessary to prepare a second edition of this volume. There was no need for a major revision of the text. However, I have taken the opportunity to make several minor changes and to correct a number of misprints. Thanks are due to those colleagues and students who made suggestions to improve the text. I am confident that this textbook will continue to serve as a useful introduction to the fascinating topic of quantum mechanics.

Frankfurt am Main,
November 1992

Walter Greiner

Preface to the First Edition

Quantum Mechanics – An Introduction contains the lectures that form part of the course of study in theoretical physics at the Johann Wolfgang Goethe University in Frankfurt. There they are given for students in physics and mathematics in their fourth semester. They are preceded by Theoretical Mechanics I (in the first semester). Theoretical Mechanics II (in the second semester), and Classical Electrodynamics (in the third semester). Quantum Mechanics I – An Introduction then concludes the foundations laid for our students of the mathematical and physical methods of theoretical physics. Graduate work begins with the courses Thermodynamics and Statistical Mechanics, Quantum Mechanics II – Symmetries, Relativistic Quantum Mechanics, Quantum Electrodynamics, the Gauge Theory of Weak Interactions, Quantum Chromodynamics, and other, more specialized lectures.

As in all the other fields mentioned, we present quantum mechanics according to the inductive method, which comes closest to the methodology of the research physicist: starting with some key experiments, which are idealized, the basic ideas of the new science are introduced step by step. In this book, for example, we present the concepts of "state of a system" and "eigenstate", which then straightforwardly lead to the basic equation of motion, i.e. to the Schrödinger equation; and, by way of a number of classic, historically important observations concerning the quantization of physical systems and the various radiation laws, we infer the duality of waves and particles, which we understand with Max Horn's conception of a "guiding field".

Quantum mechanics is then further developed with respect to fundamental problems (uncertainty relations; many-body systems; quantization of classical systems; spin within the phenomenological Pauli theory and through linearization of wave equations; etc.), applications (harmonic oscillator; hydrogen atom; Stern–Gerlach, Einstein–de Haas, Frank–Hertz, and Rabi experiments), and its mathematical structure (elements of representation theory; introduction of the S Matrix, of Heisenberg, Schrödinger, and interaction pictures; eigendifferentials and the normalization of continuum wave functions; perturbation theory; etc.). Also, the elements of angular-momentum algebra are explained, which are so essential in many applications of atomic and nuclear physics. These will be presented in a much broader theoretical context in *Quantum Mechanics – Symmetries*.

Obviously an introductory course on quantum theory cannot (and should not) cover the whole field. Our selection of problems was carried out according to

their physical importance, their pedagogical value, and their historical impact on the development of the field.

Students profit in the fourth semester at Frankfurt from the solid mathematical education of the first two years of studies. Nevertheless, in these lectures new mathematical tools and methods and their use have also to be discussed. Within this category belong the solution of special differential equations (especially of the hypergeometrical and confluent hypergeometrical differential equations), a reminder of the elements of matrix calculus, the formulation of eigenvalue problems, and the explanation of (simple) perturbation methods. As in all the lectures, this is done in close connection with the physical problems encountered. In this way the student gets a feeling for the practical usefulness of the mathematical methods. Very many worked examples and exercises illustrate and round off the new physics and mathematics.

Furthermore, biographical and historical footnotes anchor the scientific development to the general side of human progress and evolution. In this context I thank the publishers Harri Deutsch and F.A. Brockhaus (*Brockhaus Enzyklopädie*, F.A. Brockhaus, Wiesbaden – marked by BR) for giving permission to extract the biographical data of physicists and mathematicians from their publications.

The lectures are now in their 5th German edition. Over the years many students and collaborators have helped to work out exercises and illustrative examples. For the first English edition I enjoyed the help of Maria Berenguer, Snježana Butorac, Christian Derreth, Dr. Klaus Geiger, Dr. Matthias Grabiak, Carsten Greiner, Christoph Hartnack, Dr. Richard Hermann, Raffaele Mattiello, Dieter Neubauer, Jochen Rau, Wolfgang Renner, Dirk Rischke, Thomas Schönfeld, and Dr. Stefan Schramm. Miss Astrid Steidl drew the graphs and pictures. To all of them I express my sincere thanks.

I would especially like to thank Mr. Béla Waldhauser, Dipl.-Phys., for his overall assistance. His organizational talent and his advice in technical matters are very much appreciated.

Finally, I wish to thank Springer-Verlag; in particular. Dr. H.-U. Daniel, for his encouragement and patience, and Mr. Mark Seymour, for his expertise in copy-editing the English edition.

Frankfurt am Main *Walter Greiner*
July 1989

Contents

1. The Quantization of Physical Quantities 1
- 1.1 Light Quanta 1
- 1.2 The Photoelectric Effect 1
- 1.3 The Compton Effect 2
- 1.4 The Ritz Combination Principle 4
- 1.5 The Franck–Hertz Experiment 4
- 1.6 The Stern–Gerlach Experiment 5
- 1.7 Biographical Notes 5

2. The Radiation Laws 9
- 2.1 A Preview of the Radiation of Bodies 9
- 2.2 What is Cavity Radiation? 10
- 2.3 The Rayleigh–Jeans Radiation Law: The Electromagnetic Eigenmodes of a Cavity 14
- 2.4 Planck's Radiation Law 16
- 2.5 Biographical Notes 26

3. Wave Aspects of Matter 29
- 3.1 De Broglie Waves 29
- 3.2 The Diffraction of Matter Waves 34
- 3.3 The Statistical Interpretation of Matter Waves 38
- 3.4 Mean (Expectation) Values in Quantum Mechanics 43
- 3.5 Three Quantum Mechanical Operators 46
- 3.6 The Superposition Principle in Quantum Mechanics 48
- 3.7 The Heisenberg Uncertainty Principle 51
- 3.8 Biographical Notes 65

4. Mathematical Foundations of Quantum Mechanics I 67
- 4.1 Properties of Operators 67
- 4.2 Combining Two Operators 68
- 4.3 Bra and Ket Notation 69
- 4.4 Eigenvalues and Eigenfunctions 70
- 4.5 Measurability of Different Observables at Equal Times 76
- 4.6 Position and Momentum Operators 78
- 4.7 Heisenberg's Uncertainty Relations for Arbitrary Observables 79
- 4.8 Angular-Momentum Operators 81
- 4.9 Kinetic Energy 85

4.10 Total Energy 85
4.11 Biographical Notes 103

5. Mathematical Supplement 105
5.1 Eigendifferentials and the Normalization of Eigenfunctions for Continuous Spectra 105
5.2 Expansion into Eigenfunctions 108

6. The Schrödinger Equation 117
6.1 The Conservation of Particle Number in Quantum Mechanics 144
6.2 Stationary States 146
6.3 Properties of Stationary States 147
6.4 Biographical Notes 154

7. The Harmonic Oscillator 157
7.1 The Solution of the Oscillator Equation 163
7.2 The Description of the Harmonic Oscillator by Creation and Annihilation Operators 173
7.3 Properties of the Operators $\hat{a}$ and $\hat{a}^+$ 174
7.4 Representation of the Oscillator Hamiltonian in Terms of $\hat{a}$ and $\hat{a}^+$ 175
7.5 Interpretation of $\hat{a}$ and $\hat{a}^+$ 176
7.6 Biographical Notes 182

8. The Transition from Classical to Quantum Mechanics 185
8.1 Motion of the Mean Values 185
8.2 Ehrenfest's Theorem 186
8.3 Constants of Motion, Laws of Conservation 187
8.4 Quantization in Curvilinear Coordinates 190
8.5 Biographical Notes 203

9. Charged Particles in Magnetic Fields 205
9.1 Coupling to the Electromagnetic Field 205
9.2 The Hydrogen Atom 217
9.3 Three-Dimensional Electron Densities 223
9.4 The Spectrum of Hydrogen Atoms 226
9.5 Currents in the Hydrogen Atom 228
9.6 The Magnetic Moment 229
9.7 Hydrogen-like Atoms 230
9.8 Biographical Notes 244

10. The Mathematical Foundations of Quantum Mechanics II 247
10.1 Representation Theory 247
10.2 Representation of Operators 251
10.3 The Eigenvalue Problem 260
10.4 Unitary Transformations 262
10.5 The S Matrix 264
10.6 The Schrödinger Equation in Matrix Form 266

10.7 The Schrödinger Representation 269
10.8 The Heisenberg Representation 269
10.9 The Interaction Representation 270
10.10 Biographical Notes 271

11. Perturbation Theory 273
11.1 Stationary Perturbation Theory 273
11.2 Degeneracy 277
11.3 The Ritz Variational Method 292
11.4 Time-Dependent Perturbation Theory 295
11.5 Time-Independent Perturbation 300
11.6 Transitions Between Continuum States 302
11.7 Biographical Notes 327

12. Spin 329
12.1 Doublet Splitting 330
12.2 The Einstein–de Haas Experiment 332
12.3 The Mathematical Description of Spin 333
12.4 Wave Functions with Spin 336
12.5 The Pauli Equation 339
12.6 Biographical Notes 352

13. A Nonrelativistic Wave Equation with Spin 355
13.1 The Linearization of the Schrödinger Equation 355
13.2 Particles in an External Field and the Magnetic Moment 363

14. Elementary Aspects of the Quantum-Mechanical Many-Body Problem 367
14.1 The Conservation of the Total Momentum of a Particle System 371
14.2 Centre-of-Mass Motion of a System of Particles in Quantum Mechanics 373
14.3 Conservation of Total Angular Momentum in a Quantum-Mechanical Many-Particle System 377
14.4 Small Oscillations in a Many-Particle System 390
14.5 Biographical Notes 401

15. Identical Particles 403
15.1 The Pauli Principle 405
15.2 Exchange Degeneracy 405
15.3 The Slater Determinant 407
15.4 Biographical Notes 421

16. The Formal Framework of Quantum Mechanics 423
16.1 The Mathematical Foundation of Quantum Mechanics: Hilbert Space 423
16.2 Operators in Hilbert Space 426
16.3 Eigenvalues and Eigenvectors 427

需要全本请访问 www.ertongbook.com