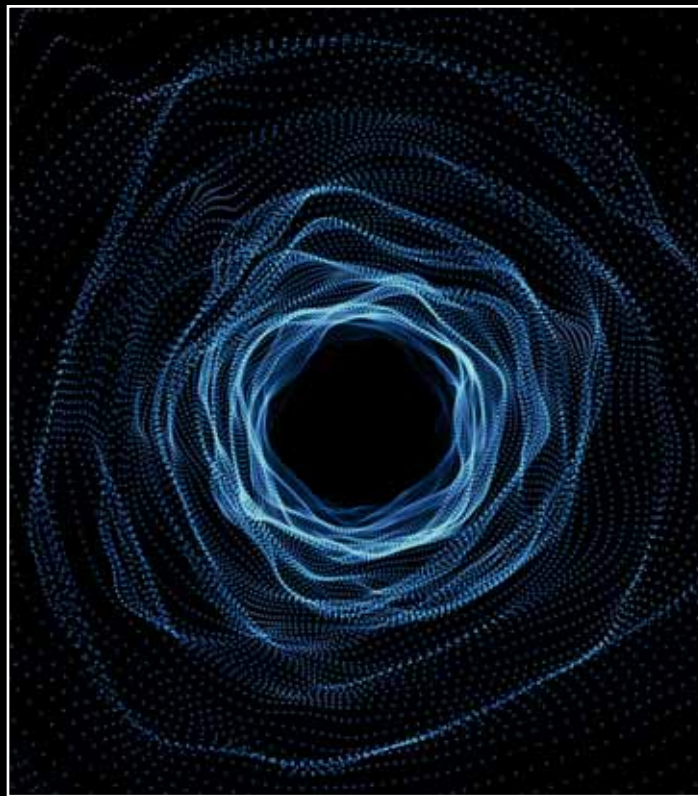


MODERN QUANTUM MECHANICS

S E C O N D E D I T I O N



J. J. Sakurai • Jim Napolitano

Modern Quantum Mechanics

Second Edition

Modern Quantum Mechanics is a classical graduate level textbook, covering the main quantum mechanics concepts in a clear, organized and engaging manner. The author, J. J. Sakurai, was a renowned theorist in particle theory. The Second Edition, revised by Jim Napolitano, introduces topics that extend the text's usefulness into the 21st century such as advanced mathematical techniques associated with quantum mechanical calculations, while at the same time retaining classic developments such as neutron interferometer experiments, Feynman path integrals, correlation measurements, and Bell's inequality. A solution manual for instructors using this textbook can be downloaded from www.cambirdge.org/napolitano under the resources tab.

The late **J.J. Sakurai**, noted theorist in particle physics, was born in Tokyo, Japan in 1933. He received his B.A. from Harvard University in 1955 and his PhD from Cornell University in 1958. He was appointed as an assistant professor at the University of Chicago, where he worked until he became a professor at the University of California, Los Angeles in 1970. Sakurai died in 1982 while he was visiting a professor at CERN in Geneva, Switzerland.

Jim Napolitano earned an undergraduate Physics degree at Rensselaer Polytechnic Institute in 1977, and a PhD in Physics from Stanford University in 1982. Since that time, he has conducted research in experimental nuclear and particle physics, with an emphasis on studying fundamental interactions and symmetries. He joined the faculty at Rensselaer in 1992 after working as a member of the scientific staff at two different national laboratories. Since 2014 he has been Professor of Physics at Temple University. He is author and co-author of over 150 scientific papers in refereed journals. Professor Napolitano maintains a keen interest in science education in general, and in particular physics education at both the undergraduate and graduate levels. He has taught both graduate and upper-level undergraduate courses in Quantum Mechanics, as well as an advanced graduate course in Quantum Field Theory.

Modern Quantum Mechanics

Second Edition

J. J. Sakurai

Deceased

Jim Napolitano

Temple University, Philadelphia



CAMBRIDGE
UNIVERSITY PRESS

University Printing House, Cambridge CB2 8BS, United Kingdom
One Liberty Plaza, 20th Floor, New York, NY 10006, USA
477 Williamstown Road, Port Melbourne, VIC 3207, Australia
4843/24, 2nd Floor, Ansari Road, Daryaganj, Delhi – 110002, India
79 Anson Road, #06–04/06, Singapore 079906

Cambridge University Press is part of the University of Cambridge.

It furthers the University's mission by disseminating knowledge in the pursuit of education, learning, and research at the highest international levels of excellence.

www.cambridge.org

Information on this title: www.cambridge.org/9781108422413

DOI: 10.1017/9781108499996

© Cambridge University Press 2017

This publication is in copyright. Subject to statutory exception and to the provisions of relevant collective licensing agreements, no reproduction of any part may take place without the written permission of Cambridge University Press.

This book was previously published by Pearson Education, Inc. 1994, 2011

Reissued by Cambridge University Press 2017

Printed in the United Kingdom by TJ International Ltd. Padstow Cornwall

A catalogue record for this publication is available from the British Library.

Additional resources for this publication available at: www.cambridge.org/napolitano

ISBN 978-1-108-42241-3 Hardback

Cambridge University Press has no responsibility for the persistence or accuracy of URLs for external or third-party internet websites referred to in this publication and does not guarantee that any content on such websites is, or will remain, accurate or appropriate.

Contents

Foreword to the First Edition	ix
Preface to the Revised Edition	xi
Preface to the Second Edition	xiii
In Memoriam	xvii
1 ■ Fundamental Concepts	1
1.1 The Stern-Gerlach Experiment	1
1.2 Kets, Bras, and Operators	10
1.3 Base Kets and Matrix Representations	17
1.4 Measurements, Observables, and the Uncertainty Relations	23
1.5 Change of Basis	35
1.6 Position, Momentum, and Translation	40
1.7 Wave Functions in Position and Momentum Space	50
2 ■ Quantum Dynamics	66
2.1 Time-Evolution and the Schrödinger Equation	66
2.2 The Schrödinger Versus the Heisenberg Picture	80
2.3 Simple Harmonic Oscillator	89
2.4 Schrödinger's Wave Equation	97
2.5 Elementary Solutions to Schrödinger's Wave Equation	103
2.6 Propagators and Feynman Path Integrals	116
2.7 Potentials and Gauge Transformations	129
3 ■ Theory of Angular Momentum	157
3.1 Rotations and Angular-Momentum Commutation Relations	157
3.2 Spin $\frac{1}{2}$ Systems and Finite Rotations	163
3.3 SO(3), SU(2), and Euler Rotations	172

- 3.4 Density Operators and Pure Versus Mixed Ensembles 178
- 3.5 Eigenvalues and Eigenstates of Angular Momentum 191
- 3.6 Orbital Angular Momentum 199
- 3.7 Schrödinger's Equation for Central Potentials 207
- 3.8 Addition of Angular Momenta 217
- 3.9 Schwinger's Oscillator Model of Angular Momentum 232
- 3.10 Spin Correlation Measurements and Bell's Inequality 238
- 3.11 Tensor Operators 246

4 ■ Symmetry in Quantum Mechanics 262

- 4.1 Symmetries, Conservation Laws, and Degeneracies 262
- 4.2 Discrete Symmetries, Parity, or Space Inversion 269
- 4.3 Lattice Translation as a Discrete Symmetry 280
- 4.4 The Time-Reversal Discrete Symmetry 284

5 ■ Approximation Methods 303

- 5.1 Time-Independent Perturbation Theory: Nondegenerate Case 303
- 5.2 Time-Independent Perturbation Theory: The Degenerate Case 316
- 5.3 Hydrogen-Like Atoms: Fine Structure and the Zeeman Effect 321
- 5.4 Variational Methods 332
- 5.5 Time-Dependent Potentials: The Interaction Picture 336
- 5.6 Hamiltonians with Extreme Time Dependence 345
- 5.7 Time-Dependent Perturbation Theory 355
- 5.8 Applications to Interactions with the Classical Radiation Field 365
- 5.9 Energy Shift and Decay Width 371

6 ■ Scattering Theory 386

- 6.1 Scattering as a Time-Dependent Perturbation 386
- 6.2 The Scattering Amplitude 391
- 6.3 The Born Approximation 399
- 6.4 Phase Shifts and Partial Waves 404
- 6.5 Eikonal Approximation 417
- 6.6 Low-Energy Scattering and Bound States 423
- 6.7 Resonance Scattering 430
- 6.8 Symmetry Considerations in Scattering 433
- 6.9 Inelastic Electron-Atom Scattering 436

7 ■ Identical Particles 446

- 7.1 Permutation Symmetry 446
- 7.2 Symmetrization Postulate 450

7.3	Two-Electron System	452	
7.4	The Helium Atom	455	
7.5	Multiparticle States	459	
7.6	Quantization of the Electromagnetic Field	472	
8	■ Relativistic Quantum Mechanics		486
8.1	Paths to Relativistic Quantum Mechanics	486	
8.2	The Dirac Equation	494	
8.3	Symmetries of the Dirac Equation	501	
8.4	Solving with a Central Potential	506	
8.5	Relativistic Quantum Field Theory	514	
A	■ Electromagnetic Units		519
A.1	Coulomb's Law, Charge, and Current	519	
A.2	Converting Between Systems	520	
B	■ Brief Summary of Elementary Solutions to Schrödinger's Wave Equation		523
B.1	Free Particles ($V = 0$)	523	
B.2	Piecewise Constant Potentials in One Dimension	524	
B.3	Transmission-Reflection Problems	525	
B.4	Simple Harmonic Oscillator	526	
B.5	The Central Force Problem [Spherically Symmetrical Potential $V = V(r)$]	527	
B.6	Hydrogen Atom	531	
C	■ Proof of the Angular-Momentum Addition Rule Given by Equation (3.8.38)		533
	Bibliography		535
	Index		537