

Contents

Preface	vii
---------	-----

List of Tables	xv
----------------	----

Topical Problems	xvii
------------------	------

PART I ■ ELEMENTARY PRINCIPLES AND APPLICATIONS TO PROBLEMS IN ONE DIMENSION	1
---	----------

1 ■ Review of Concepts of Classical Mechanics	3
--	----------

- 1.1 Generalized or “Good” Coordinates 3
- 1.2 Energy, the Hamiltonian, and Angular Momentum 6
- 1.3 The State of a System 19
- 1.4 Properties of the One-Dimensional Potential Function 24

2 ■ Historical Review: Experiments and Theories	30
--	-----------

- 2.1 Dates 30
- 2.2 The Work of Planck. Blackbody Radiation 31
- 2.3 The Work of Einstein. The Photoelectric Effect 36
- 2.4 The Work of Bohr. A Quantum Theory of Atomic States 39
- 2.5 Waves versus Particles 43
- 2.6 The de Broglie Hypothesis and the Davisson–Germer Experiment 46
- 2.7 The Work of Heisenberg. Uncertainty as a Cornerstone of Natural Law 53
- 2.8 The Work of Born. Probability Waves 55
- 2.9 Semiphilosophical Epilogue to Chapter 2 57

3 ■ The Postulates of Quantum Mechanics. Operators, Eigenfunctions, and Eigenvalues	68
3.1 Observables and Operators	68
3.2 Measurement in Quantum Mechanics	74
3.3 The State Function and Expectation Values	76
3.4 Time Development of the State Function	80
3.5 Solution to the Initial-Value Problem in Quantum Mechanics	84
4 ■ Preparatory Concepts. Function Spaces and Hermitian Operators	90
4.1 Particle in a Box and Further Remarks on Normalization	90
4.2 The Bohr Correspondence Principle	94
4.3 Dirac Notation	97
4.4 Hilbert Space	98
4.5 Hermitian Operators	104
4.6 Properties of Hermitian Operators	108
5 ■ Superposition and Compatible Observables	115
5.1 The Superposition Principle	115
5.2 Commutator Relations in Quantum Mechanics	130
5.3 More on the Commutator Theorem	137
5.4 Commutator Relations and the Uncertainty Principle	140
5.5 "Complete" Sets of Commuting Observables	143
6 ■ Time Development, Conservation Theorems, and Parity	152
6.1 Time Development of State Functions	152
6.2 Time Development of Expectation Values	168
6.3 Conservation of Energy, Linear and Angular Momentum	171
6.4 Conservation of Parity	176
7 ■ Additional One-Dimensional Problems. Bound and Unbound States	187
7.1 General Properties of the One-Dimensional Schrödinger Equation	187
7.2 The Harmonic Oscillator	190
7.3 Eigenfunctions of the Harmonic Oscillator Hamiltonian	198
7.4 The Harmonic Oscillator in Momentum Space	211
7.5 Unbound States	216
7.6 One-Dimensional Barrier Problems	222

- 7.7 The Rectangular Barrier. Tunneling 228
- 7.8 The Ramsauer Effect 235
- 7.9 Kinetic Properties of a Wave Packet Scattered from a Potential Barrier 241
- 7.10 The WKB Approximation 243
- 7.11 Principle of Least Action and Feynman's Path Integral Formulation 268

8 ■ Finite Potential Well, Periodic Lattice, and Some Simple Problems with Two Degrees of Freedom 278

- 8.1 The Finite Potential Well 278
- 8.2 Periodic Lattice. Energy Gaps 289
- 8.3 Standing Waves at the Band Edges 307
- 8.4 Brief Qualitative Description of the Theory of Conduction in Solids 313
- 8.5 Two Beads on a Wire and a Particle in a Two-Dimensional Box 317
- 8.6 Two-Dimensional Harmonic Oscillator 324
- 8.7 Linear Combination of Atomic Orbitals (LCAO) Approximation 331
- 8.8 Density of States in Various Dimensions 336

PART II ■ FURTHER DEVELOPMENT OF THE THEORY AND APPLICATIONS TO PROBLEMS IN THREE DIMENSIONS 347

9 ■ Angular Momentum 349

- 9.1 Basic Properties 349
- 9.2 Eigenvalues of the Angular Momentum Operators 358
- 9.3 Eigenfunctions of the Orbital Angular Momentum Operators \hat{L}^2 and \hat{L}_z 367
- 9.4 Addition of Angular Momentum 386
- 9.5 Total Angular Momentum for Two or More Electrons 396

10 ■ Problems in Three Dimensions 404

- 10.1 The Free Particle in Cartesian Coordinates 404
- 10.2 The Free Particle in Spherical Coordinates 410
- 10.3 The Free-Particle Radial Wavefunction 415
- 10.4 A Charged Particle in a Magnetic Field 430
- 10.5 The Two-Particle Problem 436
- 10.6 The Hydrogen Atom 446

- 10.7 Elementary Theory of Radiation 463
- 10.8 Thomas–Fermi Model 472

11 ■ Elements of Matrix Mechanics. Spin Wavefunctions 480

- 11.1 Basis and Representations 481
- 11.2 Elementary Matrix Properties 488
- 11.3 Unitary and Similarity Transformations in Quantum Mechanics 492
- 11.4 The Energy Representation 499
- 11.5 Angular Momentum Matrices 504
- 11.6 The Pauli Spin Matrices 512
- 11.7 Free-Particle Wavefunctions, Including Spin 517
- 11.8 The Magnetic Moment of an Electron 519
- 11.9 Precession of an Electron in a Magnetic Field 527
- 11.10 The Addition of Two Spins 536
- 11.11 The Density Matrix 543
- 11.12 Other “Pictures” in Quantum Mechanics 553
- 11.13 Polarization States. EPR Revisited 558
- 11.14 The Transfer Matrix 571

12 ■ Application to Atomic, Molecular, Solid-State, and Nuclear Physics. Elements of Quantum Statistics 579

- 12.1 The Total Angular Momentum, J 579
- 12.2 One-Electron Atoms 584
- 12.3 The Pauli Principle 597
- 12.4 The Periodic Table 602
- 12.5 The Slater Determinant 612
- 12.6 Application of Symmetrization Rules to the Helium Atom 614
- 12.7 The Hydrogen and Deuterium Molecules 623
- 12.8 Brief Description of Quantum Models for Superconductivity and Superfluidity 630
- 12.9 Impurity Semiconductors and the p - n Junction 641
- 12.10 Elements of Nuclear Physics. The Deuteron and Isospin 669

13 ■ Perturbation Theory 681

- 13.1 Time-Independent, Nondegenerate Perturbation Theory 681
- 13.2 Time-Independent, Degenerate Perturbation Theory 692
- 13.3 The Stark Effect 700
- 13.4 The Nearly Free Electron Model 703
- 13.5 Time-Dependent Perturbation Theory 709
- 13.6 Harmonic Perturbation 712

13.7	Application of Harmonic Perturbation Theory	718
13.8	Selective Perturbations in Time	727
13.9	Atom-Radiation Interaction	739
13.10	Hartree–Fock Model	757
14 ■	Scattering in Three Dimensions	762
14.1	Partial Waves	762
14.2	<i>S</i> -Wave Scattering	770
14.3	Center-of-Mass Frame	774
14.4	The Born Approximation	777
14.5	Atomic-Radiative Absorption Cross Section	782
14.6	Elements of Formal Scattering Theory. The Lippmann–Schwinger Equation	785
15 ■	Relativistic Quantum Mechanics	793
15.1	Preliminary Remarks	793
15.2	Klein–Gordon Equation	798
15.3	Dirac Equation	800
15.4	Electron Magnetic Moment	806
15.5	Covariant Description	810
16 ■	Quantum Computing	817
16.1	Binary Number System	817
16.2	Logic Gates	823
16.3	Turing Machine and Complexity Classes	830
16.4	Qubits and Quantum Logic Gates	832
	List of Symbols	843
	APPENDIXES	847
A ■	Additional Remarks on the \hat{x} and \hat{p} Representations	849
B ■	Spin and Statistics	853
C ■	Representations of the Delta Function	857
D ■	Differential Vector Relations	861