

Contents

Chapter 1 Dirac Formulation of Quantum Mechanics	1
1.1 Ket Vectors	5
1.2 Scalar Product; Bra Vectors	6
1.3 Linear Operators	10
1.4 Hermitian Operators	13
1.5 The Eigenvalue Problem	14
1.6 Observables, Completeness, Expansion in Eigenkets; Dirac δ Function	19
1.7 Matrices	25
1.8 Matrix Representation of Kets, Bras, and Operators	26
1.9 Transformation Functions; Change of Representation; Diagonalization	30
1.10 Quantization; Example of Continuous Spectrum	34
1.11 Measurement of Observables; Probability Interpretation	43
1.12 The Heisenberg Uncertainty Principle	45
1.13 Dynamical Behavior of a Quantum System	51
1.14 The Schrödinger Picture of Quantum Mechanics	53
1.15 The Heisenberg Picture	54
1.16 The Interaction Picture. Time-Dependent Perturbation Theory, Dyson Time Ordering Operator	57
1.17 Perturbation Theory for a Heisenberg Operator	68
	ix

1.18	Wave Mechanics	70
1.19	The Free Particle; Change in Time of Minimum Uncertainty Wave Packet	71
1.20	The Density Operator [9–13]; Perturbation Theory	74
1.21	The Reduced Density Operator	81
Chapter 2	Elementary Quantum Systems	88
PART I THE HARMONIC OSCILLATOR		
2.1	The Oscillator in the Heisenberg Picture	90
2.2	The Energy-Eigenvalue Problem for the Oscillator	94
2.3	Physical Interpretation of N , a , and a^\dagger ; Bosons and Fermions	98
2.4	Transformation Function from N to q Representation for Oscillator	102
2.5	The Coherent States [8]	104
PART II ORBITAL ANGULAR MOMENTUM; ELECTRON SPIN		
2.6	Eigenvalues and Eigenvectors of Angular Momentum	110
2.7	Particle in a Central Force Field	116
2.8	Pauli Spin Operators	122
2.9	Spin Operators in the Heisenberg Picture	127
PART III ELECTRONS IN ELECTRIC AND MAGNETIC FIELDS		
2.10	Hamiltonian for Electron in Electromagnetic Field	129
Chapter 3	Operator Algebra	132
PART I GENERAL OPERATORS		
3.1	Some General Operator Theorems	133

PART II BOSON CREATION AND ANNIHILATION OPERATORS

3.2	Ordered Boson Operators	138
3.3	Algebraic Properties of Boson Operators	150
3.4	Characteristic Functions [10]; The Wigner Distribution Function	168
3.5	The Poisson Distribution	176
3.6	The Exponential Distribution	180
3.7	Generalized Wick's Theorem for Boson Operators	182
3.8	Wick's Theorem for Boson Operators	185

PART III ARBITRARY OPERATORS

3.9	Generalization of Ordering Techniques to Arbitrary Quantum Operators [14]	190
3.10	Operator Description of Independent Atoms	196

PART IV ELEMENTARY APPLICATIONS

3.11	Solution of the Schrödinger Equation by Normal Ordering; Driven Harmonic Oscillator [15]	203
3.12	Two Weakly Coupled Oscillators	205
3.13	Distribution Function for Two-Level Atom	207
3.14	Distribution Function for Harmonic Oscillator	211
3.15	Generating Function for Oscillator Eigenfunctions	213

PART V PRINCIPLE OF MAXIMUM ENTROPY

3.16	Definition of Entropy	215
3.17	Density Operator for Spin- $\frac{1}{2}$ Particles [20]	220

Chapter 4 Quantization of the Electromagnetic Field 230

4.1	Quantization of an <i>LC</i> Circuit with a Source	231
4.2	Quantization of a Lossless Transmission Line	235

4.3	Equivalence of Classical Radiation Field in Cavity to Infinite Set of Oscillators	238
4.4	Quantization of the Radiation Field in Vacuum	246
4.5	Density of Modes	250
4.6	Commutation Relations for Fields in Vacuum at Equal Times	251
4.7	Zero-Point Field Fluctuations	256
4.8	Classical Radiation Field with Sources [7]	259
4.9	Quantization of Field with Classical Sources	261
4.10	Density Operator for Radiation Field	264
Chapter 5	Interaction of Radiation with Matter	269
5.1	Hamiltonian of an Atom in a Radiation Field	270
5.2	Absorption and Emission of Radiation by an Atom	271
5.3	Wigner–Weisskopf Theory of Natural Linewidth [2]; Lamb Shift	285
5.4	Kramers-Heisenberg Scattering Cross-Section	296
5.5	Rayleigh Scattering	301
5.6	Thomson Scattering	303
5.7	Raman Scattering	304
5.8	Resonance Fluorescence	308
5.9	The Doppler Effect [2]	309
5.10	Propagation of Light in Vacuum [1]	314
5.11	Semiclassical Theory of Electron-Spin Resonance	318
5.12	Collision Broadening of Two-Level Spin System	323
5.13	Effect of Field Quantization on Spin Resonance [7]	323
Chapter 6	Quantum Theory of Damping—Density Operator Methods	331
6.1	Model for Loss Mechanism	332
6.2	The Markoff Approximation in the Schrödinger Picture [2–5]	336

CONTENTS	xiii
6.3 The Markoff Approximation in the Heisenberg Picture [7]	360
6.4 One-Time Averages Using Associated Distribution Functions [8–10]	368
6.5 Solution of the Fokker–Planck Equation	390
6.6 Two-Time Averages, Spectra [10]	404
6.7 Rotating Wave Van der Pol Oscillator	408
Chapter 7 Quantum Theory of Damping—Langevin Approach	418
7.1 Langevin Equations of Motion for Damped Oscillator	418
7.2 Quantum Theory of Langevin Noise Sources [1]	432
7.3 Langevin Equations for a Multilevel Atom	435
7.4 Langevin Equations for N Homogeneously Broadened Three-Level Atoms	438
7.5 Langevin Theory of Noise Sources; Associated Function Formulation	441
Chapter 8 Lamb’s Semiclassical Theory of a Laser [1]	444
8.1 Modes in “Cold” Spherical Resonator	447
8.2 The Cavity Field Driven by Atoms	453
8.3 The Induced Atomic Dipole Moment	455
8.4 Adiabatic Elimination of the Atomic Variables: Properties of the Oscillator	460
Chapter 9 Statistical Properties of a Laser	469
9.1 The Laser Model [1–4]	469
9.2 The Fokker–Planck Equation for a Laser	470
9.3 The Laser Associated Langevin Equations	473
9.4 Adiabatic Elimination of Atomic Variables	474

9.5	The Laser as a Rotating Wave van der Pol Oscillator	482
9.6	Phase and Amplitude Fluctuations: Steady-State Solution, Laser Linewidth	485
Appendix A	Method of Characteristics	491
Appendix B	Hamiltonian for Radiation Field in Plane-Wave Representation	494
Appendix C	Momentum of Field in Cavity	496
Appendix D	Properties of Transverse Delta Function	498
Appendix E	Commutation Relations for D and B	501
Appendix F	Heisenberg Equations of Motion for D and B	503
Appendix G	Evaluation of Field Commutation Relations	505
Appendix H	Evaluation of Sums in Equation 5.10.17	507
Appendix I	Wiener–Khinchine Theorem	511
Appendix J	Atom-Field Hamiltonian Under Dipole Approximation	514
Appendix K	Properties of Fokker–Planck Equations	518
Index		525