

Contents

I	Mathematical Preliminaries	1
	I.1 The Mathematical Language of Quantum Mechanics	1
	I.2 Linear Spaces, Scalar Product	2
	I.3 Linear Operators, Algebras	6
II	Foundations of Quantum Mechanics — The Harmonic Oscillator	9
	II.1 Introduction	9
	II.2 The First Basic Assumption of Quantum Mechanics	10
	II.3 Algebra of the Harmonic Oscillator	15
	II.4 The Relation between Experimental Data and Quantum-Mechanical Observables	20
	II.5 The Effect of a Measurement on the State of a Quantum-Mechanical System	36
	II.6 The Basic Assumptions Applied to the Harmonic Oscillator, and Some Historical Remarks	38
	II.7 Some General Consequences of the Basic Assumptions of Quantum Mechanics	45
	II.8 Eigenvectors of Position and Momentum Operators; the Wave Functions of the Harmonic Oscillator	48
	II.9 Comparison between Quantum and Classical Harmonic Oscillators	59

II.10	Basic Assumptions II and III for Observables with Continuous Spectra	63
II.11	Position and Momentum Measurements—Particles and Waves	70
III	Energy Spectra of Some Molecules	84
III.1	Transitions between Energy Levels of Vibrating Molecules—The Limitations of the Oscillator Model	84
III.2	The Rigid Rotator	95
III.3	The Algebra of Angular Momentum	99
III.4	Rotation Spectra	105
III.5	Combination of Quantum Physical Systems—The Vibrating Rotator	112
IV	Complete Systems of Commuting Observables	125
V	Addition of Angular Momenta — The Wigner – Eckart Theorem	129
V.1	Introduction—The Elementary Rotator	129
V.2	Combination of Elementary Rotators	130
V.3	Tensor Operators and the Wigner–Eckart Theorem	138
V.4	Parity	156
VI	Hydrogen Atom — The Quantum-Mechanical Kepler Problem	171
VI.1	Introduction	171
VI.2	Classical Kepler Problem	172
VI.3	Quantum-Mechanical Kepler Problem	174
VI.4	Properties of the Algebra of Angular Momentum and the Lenz Vector	179
VI.5	The Hydrogen Spectrum	181
VII	Alkali Atoms and the Schrödinger Equation of One-Electron Atoms	189
VII.1	The Alkali Hamiltonian and Perturbation Theory	189
VII.2	Calculation of the Matrix Elements of the Operator $Q^{-\nu}$	193
VII.3	Wavefunctions and Schrödinger Equation of the Hydrogen Atom and the Alkali Atoms	199
VIII	Perturbation Theory	207
VIII.1	Perturbation of the Discrete Spectrum	207
VIII.2	Perturbation of the Continuous Spectrum—The Lippman–Schwinger Equation	213

IX	Electron Spin	218
	IX.1 Introduction	218
	IX.2 The Fine Structure—Qualitative Considerations	220
	IX.3 Fine-Structure Interaction	226
	IX.4 Fine Structure of Atomic Spectra	232
	IX.5 Selection Rules	235
	IX.6 Remarks on the State of an Electron in Atoms	235
X	Indistinguishable Particles	237
	X.1 Introduction	237
XI	Two-Electron Systems — The Helium Atom	245
	XI.1 The Two Antisymmetric Subspaces of the Helium Atom	245
	XI.2 Discrete Energy Levels of Helium	250
	XI.3 Selection Rules and Singlet–Triplet Mixing for the Helium Atom	261
	XI.4 Doubly Excited States of Helium	266
XII	Time Evolution	274
	XII.1 Time Evolution	274
	XII.A Mathematical Appendix: Definitions and Properties of Operators That Depend upon a Parameter	288
XIII	Change of the State by Dynamical Law and by the Measuring Process — The Stern – Gerlach Experiment	292
	XIII.1 The Stern–Gerlach Experiment	292
	XIII.A Appendix	303
XIV	Transitions in Quantum Physical Systems — Cross Section	306
	XIV.1 Introduction	306
	XIV.2 Transition Probabilities and Transition Rates	308
	XIV.3 Cross Sections	312

XIV.4	The Relation of Cross Sections to the Fundamental Physical Observables	314
XIV.5	Derivation of Cross-Section Formulas for the Scattering of a Beam off a Fixed Target	317
XV	Formal Scattering Theory and Other Theoretical Considerations	335
XV.1	The Lippman–Schwinger Equation	335
XV.2	In-States and Out-States	339
XV.3	The <i>S</i> -Operator and the Møller Wave Operators	347
XV.A	Appendix	335
XVI	Elastic and Inelastic Scattering for Spherically Symmetric Interactions	356
XVI.1	Partial-Wave Expansion	356
XVI.2	Unitarity and Phase Shifts	364
XVI.3	Argand Diagrams	369
XVII	Free and Exact Radial Wave Functions	372
XVII.1	Introduction	372
XVII.2	The Radial Wave Equation	373
XVII.3	The Free Radial Wave Function	376
XVII.4	The Exact Radial Wave Function	379
XVII.5	Poles and Bound States	386
XVII.6	Survey of Some General Properties of Scattering Amplitudes and Phase Shifts	388
XVII.A	Mathematical Appendix	391
XVIII	Resonance Phenomena	399
XVIII.1	Introduction	399
XVIII.2	Time Delay and Phase Shifts	404
XVIII.3	Causality Conditions	411
XVIII.4	Causality and Analyticity	414
XVIII.5	Brief Description of the Analyticity Properties of the <i>S</i> -Matrix	418
XVIII.6	Resonance Scattering—Breit–Wigner Formula for Elastic Scattering	423
XVIII.7	The Physical Effect of a Virtual State	434
XVIII.8	Argand Diagrams for Elastic Resonances and Phase-Shift Analysis	435
XVIII.9	Comparison with the Observed Cross Section: the Effect of Background and Finite Energy Resolution	439

XIX	Time Reversal	451
	XIX.1 Space-Inversion Invariance and the Properties of the S-Matrix	451
	XIX.2 Time Reversal	453
	XIX.2 Appendix to Section XIX.2	457
	XIX.3 Time-Reversal Invariance and the Properties of the S-Matrix	458
XX	Resonances in Multichannel Systems	463
	XX.1 Introduction	463
	XX.2 Single and Double Resonances	464
	XX.3 Argand Diagrams for Inelastic Resonances	478
XXI	The Decay of Unstable Physical Systems	484
	XXI.1 Introduction	484
	XXI.2 Lifetime and Decay Rate	486
	XXI.3 The Description of a Decaying State and the Exponential Decay Law	488
	XXI.4 Decay Rate	497
	XXI.5 Partial Decay Rates	499
	Epilogue	503
	Bibliography	507
	Index	511