

Contents

Preface	v
1. Introduction	1
2. Old Quantum Theory	7
2.1. Black Body Radiation	7
2.2. The Photoelectric Effect	14
2.3. Compton Scattering	16
2.4. De Broglie's Hypothesis	18
2.5. Bohr's Model of the Atom	20
2.6. Problems with Old Quantum Theory	23
2.7. Exercises	25
3. Quantum Mechanics	27
3.1. Schrödinger's Equation	28
3.2. Born's Postulate	30
3.3. Time-Independent Schrödinger Equation	31
3.4. Free Particle	33
3.5. Observables and Operators	33
3.6. The Superposition Principle	35
3.7. Expectation Values	36
3.8. The Uncertainty Principle	37
3.9. Conceptual Foundations of Quantum Mechanics	37
3.10. Exercises	41
4. Applications of Quantum Mechanics	43
4.1. Infinite Square Well	43
4.2. The Quantum Harmonic Oscillator	46
4.3. Tunnelling	48
4.4. Reflection and Transmission Coefficients	51
4.5. Tunnelling in Action	52
4.6. Two Level Systems	54
4.7. Cold Matter	55

4.8.	Exercises	59
5.	Schrödinger Equation in Three-Dimensions	63
5.1.	Three-Dimensional Box	63
5.2.	Schrödinger Equation in Spherical Coordinates	64
5.3.	Separation of Variables	68
5.4.	The Hydrogen Atom	69
5.5.	Radial Probability Densities	72
5.6.	Exercises	74
6.	Spin and Statistics	77
6.1.	Stern–Gerlach Experiment	77
6.2.	What is Spin?	79
6.3.	Symmetry of the Wave Function	80
6.4.	Wave Function for Two Identical Particles	81
6.5.	The Pauli Exclusion Principle	83
6.6.	Spin States and Spin Functions	84
6.7.	Bose–Einstein and Fermi–Dirac Distributions	85
6.8.	Exercises	90
7.	Atoms, Molecules and Lasers	91
7.1.	Periodic Table	91
7.2.	Ionisation Energies	93
7.3.	Energy Spectrum	95
7.4.	Ionic Bonding	95
7.5.	Covalent Bonding	97
7.6.	Van der Waals Force	99
7.7.	Lasers	100
7.8.	The Lasing Condition	102
7.9.	Exercises	105
8.	Formal Structure of Quantum Mechanics	107
8.1.	States and Ensembles	107
8.2.	Introduction to Dirac Notation	108
8.3.	Operators	110
8.4.	Measurements	112
8.5.	Postulates of Quantum Mechanics	114
8.6.	Position and Momentum Operators	115
8.7.	Position and Momentum Wave Functions	116
8.8.	Fourier Transforms and the Delta Function	117
8.9.	Position and Momentum Operators Revisited	120
8.10.	The Schrödinger Equation Revisited	122
8.11.	The Uncertainty Principle Revisited	123
8.12.	Pure and Mixed States	124

8.13.	Annihilation and Creation Operators	126
8.14.	The Mach–Zehnder Interferometer	128
8.15.	Perturbation Theory	132
8.16.	Exercises	136
9.	Second Revolution: Relativity	139
9.1.	Simultaneity	140
9.2.	Lorentz Transformations	140
9.3.	Length Contraction	144
9.4.	Time Dilation	145
9.5.	The Twin Paradox	147
9.6.	Causality	149
9.7.	$E = Mc^2$	150
9.8.	Relativistic Newton’s Laws of Motion	153
9.9.	General Relativity	154
9.10.	Exercises	156
10.	Relativistic Quantum Mechanics	159
10.1.	Why the Need for Relativistic Quantum Mechanics?	159
10.2.	The Klein–Gordon Equation	160
10.3.	Negative Probabilities	161
10.4.	The Dirac Equation	161
10.5.	Quantum Field Theory	163
10.6.	Outlook	166
10.7.	Exercises	167
11.	Quantum Entanglement	169
11.1.	What is Entanglement?	170
11.2.	Bell’s Inequalities	171
11.3.	Quantum Teleportation	174
11.4.	Why is Entanglement Necessary?	177
11.5.	The Non-Increase of Entanglement under Local Operations	178
11.6.	Entanglement Purification	179
11.7.	Purification of Pure States	182
11.8.	Entanglement Measures	183
11.9.	Thermodynamics of Entanglement	186
11.10.	Quantum Computing	188
11.11.	Outlook	190
11.12.	Exercises	192
12.	Solutions	193
12.1.	Chapter 2	193
12.2.	Chapter 3	196
12.3.	Chapter 4	198

12.4. Chapter 5	203
12.5. Chapter 6	205
12.6. Chapter 7	207
12.7. Chapter 8	210
12.8. Chapter 9	215
12.9. Chapter 10	217
12.10. Chapter 11	220
Bibliography	223
Index	225