

Contents

Preface

I THEORY

1 The Wave Function

- 1.1 The Schrödinger Equation
- 1.2 The Statistical Interpretation
- 1.3 Probability
 - 1.3.1 Discrete Variables
 - 1.3.2 Continuous Variables
- 1.4 Normalization
- 1.5 Momentum
- 1.6 The Uncertainty Principle
- Further Problems on Chapter 1

2 Time-Independent Schrödinger Equation

- 2.1 Stationary States
- 2.2 The Infinite Square Well
- 2.3 The Harmonic Oscillator
 - 2.3.1 Algebraic Method
 - 2.3.2 Analytic Method
- 2.4 The Free Particle
- 2.5 The Delta-Function Potential
 - 2.5.1 Bound States and Scattering States
 - 2.5.2 The Delta-Function Well
- 2.6 The Finite Square Well
- Further Problems on Chapter 2

3 Formalism

- 3.1 Hilbert Space
- 3.2 Observables
 - 3.2.1 Hermitian Operators
 - 3.2.2 Determinate States

page xi

1

3

8

11

14

16

19

20

25

25

31

39

40

48

55

61

61

63

70

76

91

94

94

94

96

Contents

3.3	Eigenfunctions of a Hermitian Operator	97
3.3.1	Discrete Spectra	98
3.3.2	Continuous Spectra	99
3.4	Generalized Statistical Interpretation	102
3.5	The Uncertainty Principle	105
3.5.1	Proof of the Generalized Uncertainty Principle	105
3.5.2	The Minimum-Uncertainty Wave Packet	108
3.5.3	The Energy-Time Uncertainty Principle	109
3.6	Vectors and Operators	113
3.6.1	Bases in Hilbert Space	113
3.6.2	Dirac Notation	117
3.6.3	Changing Bases in Dirac Notation	121
	Further Problems on Chapter 3	124
4	Quantum Mechanics in Three Dimensions	131
4.1	The Schrödinger Equation	131
4.1.1	Spherical Coordinates	132
4.1.2	The Angular Equation	134
4.1.3	The Radial Equation	138
4.2	The Hydrogen Atom	143
4.2.1	The Radial Wave Function	144
4.2.2	The Spectrum of Hydrogen	155
4.3	Angular Momentum	157
4.3.1	Eigenvalues	157
4.3.2	Eigenfunctions	162
4.4	Spin	165
4.4.1	Spin 1/2	167
4.4.2	Electron in a Magnetic Field	172
4.4.3	Addition of Angular Momenta	176
4.5	Electromagnetic Interactions	181
4.5.1	Minimal Coupling	181
4.5.2	The Aharonov–Bohm Effect	182
	Further Problems on Chapter 4	187
5	Identical Particles	198
5.1	Two-Particle Systems	198
5.1.1	Bosons and Fermions	201
5.1.2	Exchange Forces	203

5.1.3	Spin	206
5.1.4	Generalized Symmetrization Principle	207
5.2	Atoms	209
5.2.1	Helium	210
5.2.2	The Periodic Table	213
5.3	Solids	216
5.3.1	The Free Electron Gas	216
5.3.2	Band Structure	220
	Further Problems on Chapter 5	225
6 Symmetries & Conservation Laws		
6.1	Introduction	232
6.1.1	Transformations in Space	232
6.2	The Translation Operator	235
6.2.1	How Operators Transform	235
6.2.2	Translational Symmetry	238
6.3	Conservation Laws	242
6.4	Parity	243
6.4.1	Parity in One Dimension	243
6.4.2	Parity in Three Dimensions	244
6.4.3	Parity Selection Rules	246
6.5	Rotational Symmetry	248
6.5.1	Rotations About the z Axis	248
6.5.2	Rotations in Three Dimensions	249
6.6	Degeneracy	252
6.7	Rotational Selection Rules	255
6.7.1	Selection Rules for Scalar Operators	255
6.7.2	Selection Rules for Vector Operators	258
6.8	Translations in Time	262
6.8.1	The Heisenberg Picture	264
6.8.2	Time-Translation Invariance	266
	Further Problems on Chapter 6	268
II APPLICATIONS		
7 Time-Independent Perturbation Theory		
7.1	Nondegenerate Perturbation Theory	279
7.1.1	General Formulation	279
7.1.2	First-Order Theory	280

7.1.3	Second-Order Energies	284
7.2	Degenerate Perturbation Theory	286
7.2.1	Two-Fold Degeneracy	286
7.2.2	"Good" States	291
7.2.3	Higher-Order Degeneracy	294
7.3	The Fine Structure of Hydrogen	295
7.3.1	The Relativistic Correction	296
7.3.2	Spin-Orbit Coupling	299
7.4	The Zeeman Effect	304
7.4.1	Weak-Field Zeeman Effect	305
7.4.2	Strong-Field Zeeman Effect	307
7.4.3	Intermediate-Field Zeeman Effect	309
7.5	Hyperfine Splitting in Hydrogen	311
	Further Problems on Chapter 7	313
4 Quantum Mechanics in Three Dimensions		
8	The Variational Principle	327
8.1	Theory	327
8.2	The Ground State of Helium	332
8.3	The Hydrogen Molecule Ion	337
8.4	The Hydrogen Molecule	341
	Further Problems on Chapter 8	346
9	The WKB Approximation	354
9.1	The "Classical" Region	354
9.2	Tunneling	358
9.3	The Connection Formulas	362
	Further Problems on Chapter 9	371
10 Scattering		
10.1	Introduction	376
10.1.1	Classical Scattering Theory	376
10.1.2	Quantum Scattering Theory	379
10.2	Partial Wave Analysis	380
10.2.1	Formalism	380
10.2.2	Strategy	383
10.3	Phase Shifts	385
10.4	The Born Approximation	388

10.4.1	Integral Form of the Schrödinger Equation	388
10.4.2	The First Born Approximation	391
10.4.3	The Born Series	395
	Further Problems on Chapter 10	397
11 Quantum Dynamics		402
11.1	Two-Level Systems	403
11.1.1	The Perturbed System	403
11.1.2	Time-Dependent Perturbation Theory	405
11.1.3	Sinusoidal Perturbations	408
11.2	Emission and Absorption of Radiation	411
11.2.1	Electromagnetic Waves	411
11.2.2	Absorption, Stimulated Emission, and Spontaneous Emission	412
11.2.3	Incoherent Perturbations	413
11.3	Spontaneous Emission	416
11.3.1	Einstein's A and B Coefficients	416
11.3.2	The Lifetime of an Excited State	418
11.3.3	Selection Rules	420
11.4	Fermi's Golden Rule	422
11.5	The Adiabatic Approximation	426
11.5.1	Adiabatic Processes	426
11.5.2	The Adiabatic Theorem	428
	Further Problems on Chapter 11	433
12 Afterword		446
12.1	The EPR Paradox	447
12.2	Bell's Theorem	449
12.3	Mixed States and the Density Matrix	455
12.3.1	Pure States	455
12.3.2	Mixed States	456
12.3.3	Subsystems	458
12.4	The No-Clone Theorem	459
12.5	Schrödinger's Cat	461
Appendix Linear Algebra		464
A.1	Vectors	464
A.2	Inner Products	466

