CONTENTS

Preface *page* xiii

Introduction xv

1 FOUNDATIONS 1

1.1 Wave Mechanics and the Schrödinger Equation 1

1.2 Free Particles 3

1.3 Bound Particles: Quantum Well 4

1.4 Charge and Current Densities 9

1.5 Operators and Measurement 13

1.6 Mathematical Properties of Eigenstates 20

1.7 Counting States 22

1.8 Filling States: The Occupation Function 30

Further Reading 40

Exercises 41

2 ELECTRONS AND PHONONS IN CRYSTALS 45

2.1 Band Structure in One Dimension 45

2.2 Motion of Electrons in Bands 50

2.3 Density of States 54

2.4 Band Structure in Two and Three Dimensions 55

2.5 Crystal Structure of the Common Semiconductors 57

2.6 Band Structure of the Common Semiconductors 61

2.7 Optical Measurement of Band Gaps 69

2.8 Phonons 70

Further Reading 76

Exercises 76

3 HETEROSTRUCTURES 80

3.1 General Properties of Heterostructures 80
3.2 Growth of Heterostructures 82
3.3 Band Engineering 85
3.4 Layered Structures: Quantum Wells and Barriers 88
3.5 Doped Heterostructures 92
3.6 Strained Layers 96
3.7 Silicon–Germanium Heterostructures 100
3.8 Wires and Dots 102
3.9 Optical Confinement 105
3.10 Effective-Mass Approximation 107
3.11 Effective-Mass Theory in Heterostructures 111
Further Reading 114
Exercises 114

4 QUANTUM WELLS AND LOW-DIMENSIONAL SYSTEMS 118

4.1 Infinitely Deep Square Well 118
4.2 Square Well of Finite Depth 119
4.3 Parabolic Well 125
4.4 Triangular Well 128
4.5 Low-Dimensional Systems 130
4.6 Occupation of Subbands 133
4.7 Two- and Three-Dimensional Potential Wells 135
4.8 Further Confinement Beyond Two Dimensions 140
4.9 Quantum Wells in Heterostructures 142
Further Reading 146
Exercises 146

5 TUNNELLING TRANSPORT 150

5.1 Potential Step 150
5.2 T-Matrices 153
5.3 More on T-Matrices 158
5.4 Current and Conductance 162
5.5 Resonant Tunnelling 167

5.6 Superlattices and Minibands 177
5.7 Coherent Transport with Many Channels 183
5.8 Tunnelling in Heterostructures 195
5.9 What Has Been Brushed Under the Carpet? 199
Further Reading 200
Exercises 201

6 ELECTRIC AND MAGNETIC FIELDS 206
6.1 The Schrödinger Equation with Electric and Magnetic Fields 206
6.2 Uniform Electric Field 208
6.3 Conductivity and Resistivity Tensors 216
6.4 Uniform Magnetic Field 219
6.5 Magnetic Field in a Narrow Channel 233
6.6 The Quantum Hall Effect 238
Further Reading 245
Exercises 246

7 APPROXIMATE METHODS 249
7.1 The Matrix Formulation of Quantum Mechanics 249
7.2 Time-Independent Perturbation Theory 252
7.3 $\mathbf{k} \cdot \mathbf{p}$ Theory 261
7.4 WKB Theory 263
7.5 Variational Method 270
7.6 Degenerate Perturbation Theory 273
7.7 Band Structure: Tight Binding 275
7.8 Band Structure: Nearly Free Electrons 280
Further Reading 284
Exercises 284

8 SCATTERING RATES: THE GOLDEN RULE 290
8.1 Golden Rule for Static Potentials 290
8.2 Impurity Scattering 295
8.3 Golden Rule for Oscillating Potentials 301
8.4 Phonon Scattering 302

8.5 Optical Absorption 308
8.6 Interband Absorption 313
8.7 Absorption in a Quantum Well 316
8.8 Diagrams and the Self-Energy 321
Further Reading 324
Exercises 324

9 THE TWO-DIMENSIONAL ELECTRON GAS 329
9.1 Band Diagram of Modulation-Doped Layers 329
9.2 Beyond the Simplest Model 336
9.3 Electronic Structure of a 2DEG 342
9.4 Screening by an Electron Gas 349
9.5 Scattering by Remote Impurities 356
9.6 Other Scattering Mechanisms 362
Further Reading 365
Exercises 366

10 OPTICAL PROPERTIES OF QUANTUM WELLS 371
10.1 General Theory 371
10.2 Valence-Band Structure: The Kane Model 377
10.3 Bands in a Quantum Well 384
10.4 Interband Transitions in a Quantum Well 387
10.5 Intersubband Transitions in a Quantum Well 393
10.6 Optical Gain and Lasers 395
10.7 Excitons 397
Further Reading 406
Exercises 406

A1 TABLE OF PHYSICAL CONSTANTS 409

A2 PROPERTIES OF IMPORTANT SEMICONDUCTORS 410

A3 PROPERTIES OF GaAs–AlAs ALLOYS AT ROOM TEMPERATURE 412

A4 HERMITE'S EQUATION: HARMONIC OSCILLATOR 413

A5 AIRY FUNCTIONS: TRIANGULAR WELL 415

A6 KRAMERS–KRONIG RELATIONS AND RESPONSE FUNCTIONS 417

A6.1 Derivation of the Kramers–Kronig Relations 417

A6.2 Model Response Functions 419

Bibliography 423

Index 427