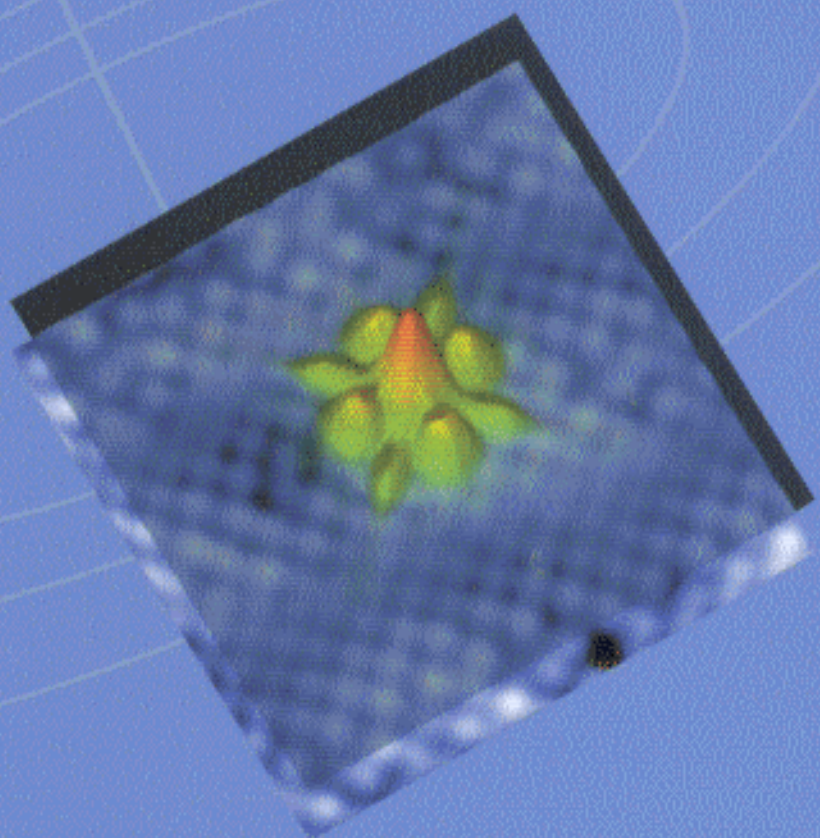


A Quantum Approach to

Condensed Matter Physics



Philip L. Taylor & Olle Heinonen

CAMBRIDGE

Contents

Preface ix

Chapter 1

Semiclassical introduction 1

- 1.1 Elementary excitations 1
- 1.2 Phonons 4
- 1.3 Solitons 7
- 1.4 Magnons 10
- 1.5 Plasmons 12
- 1.6 Electron quasiparticles 15
- 1.7 The electron–phonon interaction 17
- 1.8 The quantum Hall effect 19
- Problems 22

Chapter 2

Second quantization and the electron gas 26

- 2.1 A single electron 26
- 2.2 Occupation numbers 31
- 2.3 Second quantization for fermions 34
- 2.4 The electron gas and the Hartree–Fock approximation 42
- 2.5 Perturbation theory 50
- 2.6 The density operator 56
- 2.7 The random phase approximation and screening 60
- 2.8 Spin waves in the electron gas 71
- Problems 75

Chapter 3

Boson systems 78

- 3.1 Second quantization for bosons 78
- 3.2 The harmonic oscillator 80
- 3.3 Quantum statistics at finite temperatures 82
- 3.4 Bogoliubov's theory of helium 88
- 3.5 Phonons in one dimension 93
- 3.6 Phonons in three dimensions 99
- 3.7 Acoustic and optical modes 102
- 3.8 Densities of states and the Debye model 104
- 3.9 Phonon interactions 107
- 3.10 Magnetic moments and spin 111
- 3.11 Magnons 117
- Problems 122

Chapter 4

One-electron theory 125

- 4.1 Bloch electrons 125
- 4.2 Metals, insulators, and semiconductors 132
- 4.3 Nearly free electrons 135
- 4.4 Core states and the pseudopotential 143
- 4.5 Exact calculations, relativistic effects, and the structure factor 150
- 4.6 Dynamics of Bloch electrons 160
- 4.7 Scattering by impurities 170
- 4.8 Quasicrystals and glasses 174
- Problems 179

Chapter 5

Density functional theory 182

- 5.1 The Hohenberg–Kohn theorem 182
- 5.2 The Kohn–Sham formulation 187
- 5.3 The local density approximation 191
- 5.4 Electronic structure calculations 195
- 5.5 The Generalized Gradient Approximation 198

| | |
|--|-----|
| 5.6 More acronyms: TDDFT, CDFT, and EDFT | 200 |
| Problems | 207 |

Chapter 6

Electron–phonon interactions 210

| | |
|--|-----|
| 6.1 The Fröhlich Hamiltonian | 210 |
| 6.2 Phonon frequencies and the Kohn anomaly | 213 |
| 6.3 The Peierls transition | 216 |
| 6.4 Polarons and mass enhancement | 219 |
| 6.5 The attractive interaction between electrons | 222 |
| 6.6 The Nakajima Hamiltonian | 226 |
| Problems | 230 |

Chapter 7

Superconductivity 232

| | |
|---|-----|
| 7.1 The superconducting state | 232 |
| 7.2 The BCS Hamiltonian | 235 |
| 7.3 The Bogoliubov–Valatin transformation | 237 |
| 7.4 The ground-state wave function and the energy gap | 243 |
| 7.5 The transition temperature | 247 |
| 7.6 Ultrasonic attenuation | 252 |
| 7.7 The Meissner effect | 254 |
| 7.8 Tunneling experiments | 258 |
| 7.9 Flux quantization and the Josephson effect | 265 |
| 7.10 The Ginzburg–Landau equations | 271 |
| 7.11 High-temperature superconductivity | 278 |
| Problems | 282 |

Chapter 8

Semiclassical theory of conductivity in metals 285

| | |
|--|-----|
| 8.1 The Boltzmann equation | 285 |
| 8.2 Calculating the conductivity of metals | 288 |
| 8.3 Effects in magnetic fields | 295 |
| 8.4 Inelastic scattering and the temperature dependence of resistivity | 299 |
| 8.5 Thermal conductivity in metals | 304 |

| | |
|----------------------------|-----|
| 8.6 Thermoelectric effects | 308 |
| Problems | 313 |

Chapter 9

Mesoscopic physics 315

| | |
|---|-----|
| 9.1 Conductance quantization in quantum point contacts | 315 |
| 9.2 Multi-terminal devices: the Landauer–Büttiker formalism | 324 |
| 9.3 Noise in two-terminal systems | 329 |
| 9.4 Weak localization | 332 |
| 9.5 Coulomb blockade | 336 |
| Problems | 339 |

Chapter 10

The quantum Hall effect 342

| | |
|---|-----|
| 10.1 Quantized resistance and dissipationless transport | 342 |
| 10.2 Two-dimensional electron gas and the integer quantum Hall effect | 344 |
| 10.3 Edge states | 353 |
| 10.4 The fractional quantum Hall effect | 357 |
| 10.5 Quasiparticle excitations from the Laughlin state | 361 |
| 10.6 Collective excitations above the Laughlin state | 367 |
| 10.7 Spins | 370 |
| 10.8 Composite fermions | 376 |
| Problems | 380 |

Chapter 11

The Kondo effect and heavy fermions 383

| | |
|--|-----|
| 11.1 Metals and magnetic impurities | 383 |
| 11.2 The resistance minimum and the Kondo effect | 385 |
| 11.3 Low-temperature limit of the Kondo problem | 391 |
| 11.4 Heavy fermions | 397 |
| Problems | 403 |

Bibliography 405

Index 411