

Contents

Preface

page xi

Part I Basic concepts: electrons and phonons

1	Concept of a solid: qualitative introduction and overview	3
1.1	Classification of solids	3
1.2	A first model of a solid: interacting atoms	4
1.3	A second model: elementary excitations	6
1.4	Elementary excitations associated with solids and liquids	7
1.5	External probes	8
1.6	Dispersion curves	9
1.7	Graphical representation of elementary excitations and probe particles	13
1.8	Interactions among particles	13
2	Electrons in crystals	20
2.1	General Hamiltonian	20
2.2	The Born–Oppenheimer adiabatic approximation	21
2.3	The mean-field approximation	22
2.4	The periodic potential approximation	22
2.5	Translational symmetry, periodicity, and lattices	23
3	Electronic energy bands	31
3.1	Free electron model	31
3.2	Symmetries and energy bands	33
3.3	Nearly-free electron model	39
3.4	Tight-binding model	43
3.5	Electron (or hole) velocity in a band and the f -sum rule	48
3.6	Periodic boundary conditions and summing over band states	52
3.7	Energy bands for materials	55
4	Lattice vibrations and phonons	63
4.1	Lattice vibrations	63
4.2	Second quantization and phonons	71

4.3	Response functions: heat capacity	77
4.4	Density of states	79
4.5	Critical points and van Hove singularities	84
Part I Problems		91
Part II Electron interactions, dynamics, and responses		
5	Electron dynamics in crystals	101
5.1	Effective Hamiltonian and Wannier functions	101
5.2	Electron dynamics in the effective Hamiltonian approach	103
5.3	Shallow impurity states in semiconductors	107
5.4	Motion in external fields	108
5.5	Effective mass tensor	113
5.6	Equations of motion, Berry phase, and Berry curvature	114
6	Many-electron interactions: the homogeneous interacting electron gas and beyond	119
6.1	The homogeneous interacting electron gas or jellium model	121
6.2	Hartree–Fock treatment of the interacting electron gas	123
6.3	Ground-state energy: Hartree–Fock and beyond	126
6.4	Electron density and pair-correlation functions	130
6.5	$g(\mathbf{r}, \mathbf{r}')$ of the interacting electron gas	132
6.6	The exchange–correlation hole	135
6.7	The exchange–correlation energy	136
7	Density functional theory (DFT)	141
7.1	The ground state and density functional formalism	142
7.2	The Kohn–Sham equations	144
7.3	<i>Ab initio</i> pseudopotentials and density functional theory	150
7.4	Some applications of DFT to electronic, structural, vibrational, and related ground-state properties	152
8	The dielectric function for solids	159
8.1	Linear response theory	159
8.2	Self-consistent field framework	163
8.3	The RPA dielectric function within DFT	164
8.4	The homogeneous electron gas	166
8.5	Some simple applications	169
8.6	Some other properties of the dielectric function	173
Part II Problems		178

Part III Optical and transport phenomena

9 Electronic transitions and optical properties of solids	185
9.1 Response functions	185
9.2 The Drude model for metals	189
9.3 The transverse dielectric function	192
9.4 Interband optical transitions in semiconductors and insulators	196
9.5 Electron–hole interaction and exciton effects	201
10 Electron–phonon interactions	220
10.1 The rigid-ion model	220
10.2 Electron–phonon matrix elements for metals, insulators, and semiconductors	224
10.3 Polarons	229
11 Dynamics of crystal electrons in a magnetic field	235
11.1 Free electrons in a uniform magnetic field and Landau levels	235
11.2 Crystal electrons in a static B -field	237
11.3 Effective mass and real-space orbits	239
11.4 Quantum oscillations: periodicity in $1/B$ and the de Haas–van Alphen effect in metals	241
12 Fundamentals of transport phenomena in solids	248
12.1 Elementary treatment of magnetoresistance and the Hall effect	248
12.2 The integer quantum Hall effect	257
12.3 The Boltzmann equation formalism and transport in real materials	264
12.4 Electrical and thermal transport with the linearized Boltzmann equation	271
Part III Problems	278

Part IV Many-body effects, superconductivity, magnetism, and lower-dimensional systems

13 Using many-body techniques	287
13.1 General formalism	287
13.2 Interacting Green's functions	291
13.3 Feynman diagrams and many-body perturbation theory techniques	298
14 Superconductivity	305
14.1 Brief discussion of the experimental background	305
14.2 Theories of superconductivity	311
14.3 Superconducting quasiparticle tunneling	349

14.4 Spectroscopies of superconductors	356
14.5 More general solutions of the BCS gap equation	360
14.6 Field theoretical methods and BCS theory	368
15 Magnetism	372
15.1 Background	372
15.2 Diamagnetism	372
15.3 Paramagnetism	374
15.4 Ferromagnetism and antiferromagnetism	377
15.5 Magnetism in metals	386
15.6 Magnetic impurities and local correlation effects	389
16 Reduced-dimensional systems and nanostructures	393
16.1 Density of states and optical properties	393
16.2 Ballistic transport and quantization of conductance	399
16.3 The Landauer formula	404
16.4 Weak coupling and the Coulomb blockade	406
16.5 Graphene, carbon nanotubes, and graphene nanostructures	409
16.6 Other quasi-2D materials	421
Part IV Problems	424
<i>References</i>	434
<i>Index</i>	440