

CONTENTS

Preface to the series	vii
Preface	ix
Contents	xiii

Chapter 1. Quasi-particles in an ideal crystal 1

1.1. Band structure	1
1.2. Quasi-particles	12
1.2.1. Classical dynamics	12
1.2.2. Wave functions	17
1.3. Band structure of cubic semiconductors at the center of the Brillouin zone	22
1.3.1. Hole band	24
1.3.2. Narrow-gap semiconductors	28
1.3.3. Isotropic models	30
1.3.4. The Kane model	33
1.3.5. Gapless semiconductors	34

Chapter 2. Scattering 35

2.1. Scattering mechanisms	35
2.2. Transition probability and the principle of detailed balance	38
2.3. Scattering cross section	42
2.4. Relaxation and fluctuation characteristics of a test particle	46
2.5. The relaxation time approximation. The Boltzmann integral as a current in k -space ..	53
2.6. The method of correlators	56

<i>Chapter 3. Electron-phonon interaction</i>	63
3.1. Matrix element of a one-phonon process	63
3.2. The macrofield and microfield as two causes of scattering	67
3.3. Screening	70
3.4. Deformation potential	74
3.4.1. Acoustic deformation	75
3.4.2. Optical deformation	77
3.4.3. Deformation potential of a phonon wave	78
3.5. Macrofields	79
3.6. Matrix elements for scattering by long-wavelength phonons	83
3.7. Scattering by phonons in the pseudopotential method	84
 <i>Chapter 4. Scattering by long-wavelength phonons in a simple band</i>	 87
4.1. Matrix elements	87
4.2. Kinematics of scattering	91
4.2.1. Conservation laws in scattering by acoustic phonons, Čerenkov restrictions . .	91
4.2.2. Quasi-elastic scattering by acoustic phonons	92
4.2.3. Optical phonons	97
4.3. Relaxation times in a Boltzmann gas	98
4.3.1. Quasi-elastic scattering	98
4.3.2. Acoustic phonons	99
4.3.3. Optical phonons	101
4.4. Relaxation times in a Fermi gas	103
4.4.1. High temperatures	104
4.4.2. Low temperatures	105
4.5. Fluctuation-dissipation theorem for quasi-elastic scattering	107
 <i>Chapter 5. Scattering by phonons in an anisotropic electron band</i>	 109
5.1. Deformation potential scattering in an ellipsoidal valley	109
5.1.1. Acoustic phonons	109
5.1.2. Optical phonons	117
5.2. Intervalley scattering	118
5.2.1. Intervalley transitions	118
5.2.2. Scattering times	119
5.3. Intervalley scattering experiments	124
5.3.1. Magnetophonon resonance	124

5.3.2. The electroacoustic effect and sound absorption	124
5.3.3. Temperature dependence of mobility	126
5.3.4. Hot electrons	126
5.4. Diffusion on the Fermi surface	128
 <i>Chapter 6. Electron–electron scattering and the electron temperature</i>	 132
6.1. Probability of electron–electron scattering	132
6.2. Characteristics of test electron scattering by an electron gas	134
6.2.1. Boltzmann gas	135
6.2.2. Fermi gas	138
6.2.3. Fast test electrons	143
6.3. Effect of electron–electron scattering on the distribution function	143
6.3.1. An example: gallium arsenide	145
6.4. Electron temperature relaxation	150
6.4.1. Acoustic phonons	151
6.4.2. Optical phonons	153
6.5. Effect of electron–electron scattering on the oscillating photoresponse	158
6.6. Electron temperature relaxation time measurement	161
6.6.1. Thermometry based on Shubnikov–de Haas oscillations	161
6.6.2. Mobility dynamics	164
6.6.3. Radiation heating	165
 <i>Chapter 7. Relaxation characteristics of kinetic effects</i>	 168
7.1. Distribution function perturbation in various types of experiments	168
7.2. Averaging over energies	175
7.3. Mobility in semiconductors	179
7.4. Umklapp collisions	182
7.5. Relaxation upon mutual scattering of various types of carriers	188
7.5.1. DC conductivity	190
7.5.2. Magnetoresistance	191
7.5.3. High-frequency conductivity	192
7.6. Temperature dependences of kinetic effects in metals and semimetals	193
7.6.1. Scattering by phonons	194
7.6.2. Electron–electron scattering	198
7.6.3. Semimetals	199
 <i>Chapter 8. Two-phonon processes</i>	 201
8.1. Probabilities of two-phonon transitions	201
8.2. Real and virtual transitions. Compound scattering	205

8.2.1. Optical phonons	207
8.2.2. Acoustic phonons	209
8.3. Interaction with short-wavelength phonons	212
 <i>Chapter 9. Scattering by impurities</i>	 215
9.1. Neutral impurities in semiconductors	215
9.2. Charged impurities in semiconductors	218
9.2.1. Intravalley scattering by a Coulomb potential	218
9.2.2. Intervalley scattering	222
9.3. Partial phase shifts in metals	225
9.3.1. The Friedel sum rule	225
9.3.2. Anisotropy of scattering by impurities	230
9.4. Resonant scattering by virtual d-levels	233
 <i>Chapter 10. Scattering by dislocations</i>	 241
10.1. Scattering diameter	241
10.2. Experimental investigations	247
10.2.1. Metals	247
10.2.2. Semiconductors	251
 <i>Chapter 11. Scattering by a crystal surface</i>	 253
11.1. General definitions	253
11.2. Coherent scattering	254
11.2.1. Kinematics	254
11.2.2. Transition probabilities	258
11.2.3. Intergranular and interphase boundaries	260
11.3. Observation of coherent scattering	262
11.3.1. Magnetic surface levels	262
11.3.2. Transverse focusing	263
11.3.3. Size effect	265
11.3.4. Static skin effect	267
11.4. Incoherent scattering	269
11.4.1. Point imperfections	270
11.4.2. Specular roughness	271
11.4.3. Matte roughness	273

Chapter 12. Scattering in a degenerate band and in a multiband model . . .	275
12.1. Matrix elements for quasi-particle scattering by phonons	275
12.2. Overlap factors	279
12.3. The isotropic model for hole scattering by phonons in a degenerate band	282
12.3.1. Acoustic phonons	282
12.3.2. Optical phonons	285
12.4. Cyclotron resonance of hot holes in germanium	287
12.5. Scattering by the deformation potential of acoustic phonons in the multiband model	291
12.6. Interband transitions with LO-phonon emission	297
12.7. Electron scattering by holes	301
12.8. Scattering by ionized impurities	303
 Chapter 13. Spin-flip induced by spin-orbit interaction	 306
13.1. Spin-flip time	306
13.2. Scattering by nonmagnetic impurities	308
13.2.1. Spin-flip mechanisms	308
13.2.2. Spin-flip with small momentum transfer	311
13.2.3. Spin-flip in the Kane model	312
13.3. Scattering by phonons	316
13.3.1. Selection rules	316
13.3.2. Time for spin-flip due to the deformation potential of acoustic phonons	317
13.4. Precession mechanism of spin relaxation	319
13.5. Spin relaxation in metals – experimental data	321
13.5.1. Phonons	323
13.5.2. Dislocations	325
13.5.3. Impurities	326
13.6. Spin relaxation in semiconductors – experimental data	330
13.6.1. Impurity scattering. The spin resonance method	330
13.6.2. Spin alignment	330
13.6.3. Hot luminescence. Wavevector alignment	336
13.7. Spin-flip at a surface	338
 Chapter 14. The effect of a magnetic field on scattering	 340
14.1. States in a magnetic field and the description of scattering	340
14.2. The effect of Larmor motion on relaxation	345
14.2.1. Optical phonon emission in crossed fields	345
14.2.2. Diffusion over the Fermi surface	349
14.2.3. Precessional spin relaxation	351
14.3. Scattering by acoustic phonons in an ultraquantum field – Boltzmann gas	353

14.3.1.	Matrix elements and relaxation times	353
14.3.2.	Kinematics	354
14.3.3.	Relaxation times for scattering in the lowest Landau band	357
14.4.	Scattering by phonons in a quantized Fermi gas	361
14.5.	Resonance inelastic scattering	368
14.5.1.	Magnetophonon resonance	369
14.5.2.	Cyclotron resonance linewidth	370
14.5.3.	Magnetoimpurity resonance	370
14.6.	Static imperfections	372
14.6.1.	Impurities	372
14.6.2.	Macroscopic inclusions with sharp boundaries	375
14.7.	Electron-electron scattering in the ultraquantum limit	376
14.7.1.	The Coulomb singularity and the density of states singularity	377
14.7.2.	Establishing of the Maxwell distribution in the lowest Landau band	379
14.7.3.	Energy relaxation	381
14.8.	Spin-flip is a quantizing magnetic field – Kane model	383
 <i>Chapter 15. Exchange and spin interaction</i>		 390
15.1.	Interaction between a conduction electron and a magnetic atom	390
15.2.	Scattering by a spin lattice	393
15.2.1.	Scattering probability	394
15.2.2.	The paramagnetic region – $T > T_c$	397
15.2.3.	The ferromagnetic region – $T < T_c$	399
15.2.4.	The critical region – $T \approx T_c$	400
15.2.5.	Electrical resistivity of rare-earth metals	401
15.3.	Magnetic impurities	405
15.4.	Skew scattering	409
15.4.1.	Spin-aligned band electrons	410
15.4.2.	Magnetic atoms with aligned spins	412
15.4.3.	Extraordinary Hall effect	413
15.5.	Electron spin relaxation in exchange interaction with holes	417
15.5.1.	Rate of spin-flip	417
15.5.2.	Spin relaxation in GaAs and GaSb	422
15.5.3.	Effect of elastic scattering on spin relaxation	424
 Appendix. Parameters of certain semiconductor materials		 426
References		429
Author index		437
Subject index		443
Materials index		447
Cumulative index		451