

Contents

Preface	xiii
1 Basic concepts	1
1.1 Introduction	1
1.2 Conduction electron scattering in solids	1
1.3 Scattering anisotropy	7
1.4 Effects of the scale of microstructure	7
1.5 Matthiessen's rule	9
1.6 Simple and non-simple metals	10
1.7 Elastic and inelastic scattering	15
1.7.1 Electron and phonon energies	15
1.7.2 Conservation of momentum	15
1.7.3 Magnetic scattering	16
1.8 The Boltzmann equation and relaxation time	17
1.8.1 Wavepackets	17
1.8.2 The linearised Boltzmann equation	21
1.8.3 The relaxation time approximation	22
1.8.4 Calculation of the resistivity in the relaxation time approximation	22
1.8.5 Other solutions of the Boltzmann equation – anisotropic relaxation times	24
1.8.6 Other formalisms	28
2 Atomic configuration of an alloy	30
2.1 Dilute and concentrated alloys	30
2.2 Correlation parameters in crystalline materials	30
2.3 Composition waves	39
2.4 Reciprocal space representation	40
2.5 Short range atomic configurations	41
2.5.1 Mode of decomposition	41
2.5.2 Phase separation	43
(a) Clustering	43
(b) Precipitation	45
(c) Spinodal decomposition	46
2.5.3 Atomic ordering	49
(a) Type I homogeneous (statistical) SRO	49

viii *Contents*

	(b) Type II(a) heterogeneous SRO (microdomain model)	50
	(c) Type II(b) heterogeneous SRO (antiphase domain model)	50
2.6	Long range atomic correlations	50
	2.6.1 Long range ordering	51
	2.6.2 Two-phase mixtures	54
	2.6.3 Some general comments	54
2.7	Atomic displacement effects	57
	2.7.1 Atomic size effects	58
	2.7.2 Dynamic atomic displacements	61
	(a) Einstein model	61
	(b) Debye model	63
	2.7.3 Displacive phase transitions	67
2.8	Amorphous alloys	69
	2.8.1 Static atomic structure	71
	2.8.2 Dynamic fluctuations	75
3	The structure of magnetic materials	76
3.1	Collective electron and localised moment models	76
3.2	Magnetic configuration	80
	3.2.1 Isolated moments	80
	3.2.2 Spin glasses	84
	3.2.3 Magnetic clusters	87
	3.2.4 Long range magnetic order, $T < T_c$	89
	3.2.5 Short range magnetic order, $T > T_c$	94
	3.2.6 Magnons	95
3.3	Nearly magnetic metals – spin fluctuations	98
3.4	Effects of atomic rearrangements	102
	3.4.1 Long range effects	103
	3.4.2 Short range effects	104
4	Electrons in simple metals and alloys	107
4.1	Scattering potentials and electron wavefunctions	107
4.2	Pseudo- and model potentials	115
4.3	Electron–electron interactions	119
	4.3.1 Screening in metals	120
	4.3.2 Exchange and correlation	122
4.4	Nearly free electron theory	124
4.5	The scattering matrix	127
	4.5.1 The first and second Born approximations	128
	4.5.2 Factorisation of the matrix elements	129

	<i>Contents</i>	ix
	4.5.3 The pseudopotential in alloys	130
	4.5.4 The pseudopotential in a deformed lattice	134
5	Electrical resistivity of simple metals and alloys	137
5.1	A general resistivity expression	138
5.2	The resistivity of alloys with short range atomic correlations	139
	5.2.1 Homogeneous atomic correlations	141
	5.2.2 Inhomogeneous atomic correlations	143
	(a) Small zone limit	145
	(b) Intermediate zone size	147
	(c) Large zone limit	150
5.3	Homogeneous long range atomic ordering	160
	5.3.1 Conduction electron scattering effects	160
	(a) Bragg–Williams model	162
	(b) Coexisting long and short range ordering	162
	5.3.2 Electron band structure effects	164
5.4	Inhomogeneous long range ordering	167
5.5	Long range phase separation	169
	5.5.1 Scale of phase separation $\gg \Lambda$	170
	5.5.2 Scale of phase separation $\sim \Lambda$	184
5.6	Atomic displacement effects	195
	5.6.1 Point defects and displacements	195
	(a) Vacancy	195
	(b) Substitutional impurity	197
	(c) Self-interstitials	197
	(d) Impurity interstitial	198
	5.6.2 Thermally induced displacements	198
	5.6.3 Static atomic displacements in a concentrated alloy	203
	5.6.4 Displacive transitions	207
	5.6.5 Combined effects	208
5.7	Some applications	212
	5.7.1 Phonon scattering	212
	(a) Alkali metals	213
	(b) Noble metals	218
	5.7.2 Residual resistivity of disordered random solid solutions	220
	(a) Dilute alloys	221
	(b) Concentrated alloys	236
	5.7.3 Homogeneous short range atomic correlations	237
	5.7.4 Long range ordering	253

x *Contents*

5.7.5	Precipitation	257
5.7.6	Long range phase separation	261
(a)	Scale of phase separation $\gg \Lambda$	261
(b)	Scale of phase separation $\leq \Lambda$	264
5.7.7	Displacive transitions	271
6	Non-simple, non-magnetic metals and alloys	272
6.1	Band structure and the electrical resistivity	273
6.2	Models and pseudopotentials in non-simple metals	274
6.3	The phase shift method	279
6.4	The T -matrix	284
6.5	Advanced phase shift methods: the KKR-Green's function method	287
6.6	Some applications	289
6.6.1	Pure noble and transition metals	289
6.6.2	Dilute alloys: bound and virtual bound states	291
6.7.	Concentrated alloys	300
6.7.1	First-order theories: the virtual crystal and rigid band approximations	300
6.7.2	Advanced theories: the average t -matrix approximation (ATA) and coherent potential approximation (CPA)	306
7	Magnetic and nearly magnetic alloys	318
7.1	Magnetic materials with long range magnetic order	318
7.1.1	Overview	318
7.1.2	Two-sub-band model	323
7.2	Local environment effects and magnetic clusters	334
7.3	Nearly magnetic systems: local spin fluctuations	339
7.3.1	Kondo alloys	339
7.3.2	Exchange-enhanced alloys	341
7.3.3	Composition dependence	345
7.3.4	Nearly magnetic pure metals and concentrated alloys	348
7.4	Spin glasses	351
8	Other phenomena	356
8.1	Resistivity at the critical point	356
8.1.1	Some general comments	356
8.1.2	The electrical resistivity near T_c	358
(a)	Ferromagnets	363
(b)	Antiferromagnets	365

Contents xi

(c) Atomic order-disorder	366
(d) Miscibility gap	368
8.2.1 Related phenomena	370
8.2. Highly resistive materials	372
8.2.1 Some general observations	372
8.2.2 $\Lambda > a_0$	375
(a) Diffraction models and the Debye-Waller factor	375
(b) CPA, interband and other band-based calculations	377
8.2.3 $\Lambda \sim a_0$	378
8.2.4 Some general comments	379
8.3 Amorphous metals	380
8.3.1 General observations	380
8.3.2 Resistivity in non-magnetic glasses	382
(a) $T \geq \Theta_D$	382
(b) $\Theta_D > T > 0$	386
8.3.3 Resistivity of metallic glasses containing magnetic components	388
(a) Ferromagnetic behaviour	388
(b) Spin glasses	389
8.3.4 Resistivity minima	391
Appendices	
A Units	393
B Integrations over $d\mathbf{k}$, dS , dE and $d\Omega$	394
C The average $\langle \exp(i\mathbf{x}) \rangle$	396
D High and low temperature limits of $\rho_p(T)$	397
E Determination of $2k_F R_i$ in a nearly free electron solid	398
References	
Index	399
	421