Contents

Authors' introduction --- V

1	Phenomenological thermodynamics of irreversible processes — 1
1.1	Main postulates of non-equilibrium thermodynamics —— 1
1.1.1	Thermodynamic description of equilibrium and non-equilibrium
	systems —— 1
1.1.2	Local equilibrium principle —— 3
1.1.3	Entropy balance equation and conservation laws —— 4
1.1.4	Generalized flows and generalized thermodynamic forces — 7
1.1.5	Generalized transport coefficients and the Onsager symmetry relations —— 9
1.1.6	Variational principles in linear non-equilibrium thermodynamics —— 10
1.1.7	Minimum entropy production principle for weakly non-equilibrium steady states —— 12
1.2	On the application of the Onsager theory —— 14
1.2.1	Thermoelectric phenomena. The Peltier, Seebeck, Thomson effects and
	their relationship —— 14
1.2.2	Effects in an external magnetic field —— 20
1.3	Self-organization in highly non-equilibrium systems —— 29
1.3.1	Non-equilibrium dissipative structures —— 29
1.3.2	The Glansdorff-Prigogine universal evolution criterion —— 30
1.3.3	Ways of describing strongly non-equilibrium systems —— 32
1.3.4	Stability of states of highly non-equilibrium systems —— 35
1.3.5	The Lyapunov global stability criterion —— 37
1.3.6	Dynamical systems with one degree of freedom —— 39
1.3.7	Dynamical systems with two degrees freedom —— 41
1.3.8	Dynamic chaos —— 47
1.3.9	Dynamic chaos in one-dimensional mappings —— 52
1.4	Problems to Chapter 1 —— 58
2	Brownian motion —— 61
2.1	The Langevin equation for a Brownian particle —— 61
2.1.1	Nature of motion of a Brownian particle. Random forces —— 61
2.1.2	Displacement of a Brownian particle —— 66
2.2	The Fokker–Planck equation for a Brownian particle —— 69
2.2.1	Derivation of the Fokker-Planck equation —— 69
2.2.2	The solution of the Fokker-Planck equation —— 71
2.3	Problems to Chapter 2 —— 75

3 Kinetic equations in non-equilibrium statistical mechanics — 77



3.1	Description of non-equilibrium systems in statistical mechanics ——77
3.1.1	Integrable and nonintegrable dynamical systems — 77
3.1.2	The evolution of dynamical systems in phase space —— 79
3.2	Substantiation of quasiclassical kinetic equations —— 86
3.2.1	The Liouville equation for the distribution function — 86
3.2.2	The chain of the Bogoliubov equations —— 87
3.2.3	Equation for the one-particle distribution. The relaxation time approximation —— 91
3.2.4	The Vlasov kinetic equation for a collisionless plasma —— 93
3.2.5	The Boltzmann equation for a low-density gas —— 100
3.2.6	Qualitative derivation of the Boltzmann equation —— 101
3.2.7	Derivation of the Boltzmann equation from the Bogoliubov equations chain —— 107
3.2.8	The Fokker–Planck equation —— 111
3.3	Solving for kinetic equations —— 115
3.3.1	The solution of the Boltzmann equation for the equilibrium state —— 115
3.3.2	The Boltzmann <i>H</i> -theorem —— 117
3.3.3	The Hilbert expansion —— 119
3.3.4	The Enskog-Chapman method. Derivation of hydrodynamic
J.J. 4	equations —— 125
3.3.5	The method of moments —— 130
3.4	Problems to Chapter 3 —— 132
4	Kinetic equation for electrons and phonons in conducting crystals —— 135
4.1	Kinetic coefficients in the relaxation time approximation —— 135
4.1.1	Kinetic equation for electrons and its solution to the relaxation time approximation —— 135
4.1.2	Conditions of applicability for the quasi-classical description of electrons in conducting crystals —— 140
4.1.3	How to determine charge and heat fluxes and calculate kinetic coefficients when $H = 0 - 143$
4.1.4	Scattering of electrons by lattice vibrations —— 154
4.1.5	The Hamiltonian of interaction between electrons and charged impurity centers —— 157
4.1.6	The collision integral for the electron-phonon interaction —— 160
4.1.7	Phenomenon of phonon drag —— 165
4.1.8	Expressions for charge and heat fluxes in a magnetic field. Tensor
	structure of kinetic coefficients —— 169
4.1.9	Galvanomagnetic and thermomagnetic effects in semiconductors with a parabolic dispersion law —— 171
4.2	Hydrodynamic description of a hot electrons —— 177
4.2.1	Transition to a hydrodynamic description —— 177

4.2.2	The momentum balance equation —— 180
4.2.3	Balance equations of energy and particle number —— 185
4.2.4	Solving a set of balance equations. Applications of hydrodynamic
	approach —— 188
4.2.5	Negative differential resistance —— 190
4.3	Problems to Chapter 4 —— 194
5	Theory of linear response to an external mechanical perturbation —— 197
5.1	Electrical conductivity of an electron gas. The Kubo method —— 197
5.1.1	The Liouville equation and its solution —— 197
5.1.2	Linear response of a dynamical system to an external field —— 201
5.1.3	Calculation of electrical conductivity —— 206
5.1.4	High-frequency magnetic susceptibility —— 216
5.2	Electrical conductivity in a quantizing magnetic field —— 223
5.2.1	Charge and heat fluxes in a quantizing magnetic field —— 223
5.2.2	Dynamics of electron motion in a quantizing magnetic field —— 225
5.2.3	The conductivity tensor in a quantizing magnetic field —— 228
5.2.4	The conductivity in the case quasi-elastic scattering by phonons —— 230
5.3	Symmetry properties of correlation functions —— 237
5.3.1	Additive conservation laws and selection rules for averages —— 237
5.3.2	Symmetry properties of correlation functions for operations of spatial
	rotation, complex conjugation and time reversal —— 240
5.4	Problems to Chapter 5 —— 245
6	Non-equilibrium statistical operator method —— 249
6.1	Non-equilibrium and quasi-equilibrium statistical operators —— 249
6.1.1	Quasi-equilibrium distribution —— 249
6.1.2	Extremal properties of a quasi-equilibrium distribution.
	Thermodynamics of a quasi-equilibrium ensemble —— 252
6.1.3	Boundary conditions and the Liouville equation for the NSO —— 259
6.1.4	Linear relaxation equations in the NSO-method —— 262
6.2	The projection operators method in non-equilibrium statistical mechanics —— 268
6.2.1	Why is it necessary to introduce projection operators? —— 268
6.2.2	The Mori projection operator method —— 272
6.2.3	Using the Mori projection operators to calculate conductivity —— 279
6.2.4	Relationship between a linear variant of the NSO-method and Mori's
	method —— 286
6.2.5	High-frequency susceptibility —— 290
6.2.6	Determination of non-equilibrium parameters by the
	NSO-method — 292

6.3	Hydrodynamic modes and singularity of dynamic correlation functions —— 298
6.3.1	Spin diffusion — 298
6.3.2	The fluctuation-dissipation theorem —— 302
6.3.3	Long-range correlations and slow modes —— 307
6.3.4	Bogoliubov inequality and $1/k^2$ divergence theorem — 312
6.4	Problems to Chapter 6 —— 318
7	Physical principles of spintronics —— 321
7.1	Spin current — 321
7.1.1	Nature of spin current emergence —— 321
7.1.2	Kinetic equation in the relaxation time approximation for the
	two-channel Mott model —— 324
7.2	Magnetoresistance and spin accumulation in layered structures —— 327
7.2.1	Giant magnetoresistance —— 327
7.2.2	Spin accumulation —— 337
7.2.3	Spin-induced voltage detection —— 340
7.2.4	Using the Hanle effect to detect spin accumulation —— 341
7.2.5	Coordinate-dependence of electrochemical potentials in an F/N
	structure —— 343
7.3	The spin Hall effect —— 349
7.3.1	Phenomenological consideration —— 349
7.3.2	Spin-orbit interaction mechanisms —— 352
7.3.3	The microscopic nature of spin transport —— 356
7.3.4	A qualitative explanation of the intrinsic spin Hall effect for systems with
	the Rashba Hamiltonian —— 358
7.3.5	The Berry phase. Basic definitions —— 365
7.3.6	The Berry phase for Bloch electrons —— 369
7.3.7	Dynamics of Bloch electrons in an electric field —— 372
7.3.8	The Berry curvature and the spin Hall effect —— 373
7.3.9	Physical principles of operation of spintronics devices —— 375
7.4	Problems to the Chapter 7 —— 378
8	Response of a highly non-equilibrium system to a weak measuring field —— 381
8.1	NSO for highly non-equilibrium systems —— 381
8.1.1	Set up of the problem. A boundary condition for the NSO —— 381
8.1.2	Generalized susceptibility of a non-equilibrium system —— 387
8.2	Projection operator for non-equilibrium systems —— 392
8.2.1	Magnetic susceptibility —— 392
8.2.2	Electrical conductivity of highly non-equilibrium systems —— 394
8.3	Problems to Chapter 8 —— 411

9	Master equation approach —— 413
9.1	The basic idea of the method —— 413
9.1.1	Problem statement —— 413
9.1.2	The Zwanzig kinetic equation —— 414
9.2	Master equation for the quasi-equilibrium distribution —— 417
9.2.1	Robertson projection operator —— 417
9.2.2	Use of the master equation to calculate kinetic coefficients — 420
9.3	Problems to Chapter 9 —— 426
- · · · ·	. 1

Bibliography — 429

Index —— 431