# Contents


**1 Basic Concepts of Thermodynamics and Statistical Physics** ..... 1

1.1 Macroscopic Description of State of Systems: Postulates of Thermodynamics ..... 1

1.2 Mechanical Description of Systems: Microscopic State: Phase Space: Quantum States ..... 6

1.3 Statistical Description of Classical Systems: Distribution Function: Liouville Theorem ..... 13

1.4 Microcanonical Distribution: Basic Postulate of Statistical Physics ..... 19

1.5 Statistical Description of Quantum Systems: Statistical Matrix: Liouville Equation ..... 22

1.6 Entropy and Statistical Weight ..... 27

1.7 Law of Increasing Entropy: Reversible and Irreversible Processes ..... 31

1.8 Absolute Temperature and Pressure: Basic Thermodynamic Relationship ..... 35

**2 Law of Thermodynamics: Thermodynamic Functions** ..... 43

2.1 First Law of Thermodynamics: Work and Amount of Heat: Heat Capacity ..... 43

2.2 Second Law of Thermodynamics: Carnot Cycle ..... 50

2.3 Thermodynamic Functions of Closed Systems: Method of Thermodynamic Potentials ..... 56

2.4 Thermodynamic Coefficients and General Relationships Between Them ..... 63

2.5 Thermodynamic Inequalities: Stability of Equilibrium State of Homogeneous Systems ..... 69

2.6 Third Law of Thermodynamics: Nernst Principle ..... 74

2.7 Thermodynamic Relationships for Dielectrics and Magnetics .. 79

2.8 Magnetocaloric Effect: Production of Ultra-Low Temperatures ... 83
2.9 Thermodynamics of Systems with Variable Number of Particles: Chemical Potential ... 86
2.10 Conditions of Equilibrium of Open Systems ... 90

**3 Canonical Distribution: Gibbs Method** ... 93
3.1 Gibbs Canonical Distribution for Closed Systems ... 93
3.2 Free Energy: Statistical Sum and Statistical Integral ... 99
3.3 Gibbs Method and Basic Objects of its Application ... 102
3.4 Grand Canonical Distribution for Open Systems ... 103

**4 Ideal Gas** ... 109
4.1 Free Energy, Entropy and Equation of the State of an Ideal Gas ... 109
4.2 Mixture of Ideal Gases: Gibbs Paradox ... 112
4.3 Law About Equal Distribution of Energy Over Degrees of Freedom: Classical Theory of Heat Capacity of an Ideal Gas ... 115
4.3.1 Classical Theory of Heat Capacity of an Ideal Gas ... 118
4.4 Quantum Theory of Heat Capacity of an Ideal Gas: Quantization of Rotational and Vibrational Motions ... 120
4.4.1 Translational Motion ... 122
4.4.2 Rotational Motion ... 125
4.4.3 Vibrational Motion ... 128
4.4.4 Total Heat Capacity ... 131
4.5 Ideal Gas Consisting of Polar Molecules in an External Electric Field ... 133
4.5.1 Orientational Polarization ... 133
4.5.2 Entropy: Electrocaloric Effect ... 137
4.5.3 Mean Value of Energy: Caloric Equation of State ... 138
4.5.4 Heat Capacity: Determination of Electric Dipole Moment of Molecule ... 139
4.6 Paramagnetic Ideal Gas in External Magnetic Field ... 141
4.6.1 Classical Case ... 141
4.6.2 Quantum Case ... 143
4.7 Systems with Negative Absolute Temperature ... 150

**5 Non-Ideals Gases** ... 157
5.1 Equation of State of Rarefied Real Gases ... 157
5.2 Second Virial Coefficient and Thermodynamics of Van Der Waals Gas ... 164
5.3 Neutral Gas Consisting of Charged Particles: Plasma ... 169

**6 Solids** ... 175
6.1 Vibration and Waves in a Simple Crystalline Lattice ... 175
6.1.1 One-Dimensional Simple Lattice ... 178
6.1.2 Three-Dimensional Simple Crystalline Lattice ... 182
6.2 Hamilton Function of Vibrating Crystalline Lattice: Normal Coordinates ... 184
6.3 Classical Theory of Thermodynamic Properties of Solids ... 187
6.4 Quantum Theory of Heat Capacity of Solids: Einstein and Debye Models ... 194
6.4.1 Einstein's Theory ... 196
6.4.2 Debye's Theory ... 197
6.5 Quantum Theory of Thermodynamic Properties of Solids ... 204

**7 Quantum Statistics: Equilibrium Electron Gas** ... 213
7.1 Boltzmann Distribution: Difficulties of Classical Statistics ... 214
7.2 Principle of Indistinguishability of Particles: Fermions and Bosons ... 222
7.3 Distribution Functions of Quantum Statistics ... 229
7.4 Equations of States of Fermi and Bose Gases ... 234
7.5 Thermodynamic Properties of Weakly Degenerate Fermi and Bose Gases ... 237
7.6 Completely Degenerate Fermi Gas: Electron Gas: Temperature of Degeneracy ... 240
7.7 Thermodynamic Properties of Strongly Degenerate Fermi Gas: Electron Gas ... 244
7.8 General Case: Criteria of Classicity and Degeneracy of Fermi Gas: Electron Gas ... 249
7.8.1 Low Temperatures ... 250
7.8.2 High Temperatures ... 251
7.8.3 Moderate Temperatures: $T \approx T_0$ ... 251
7.9 Heat Capacity of Metals: First Difficulty of Classical Statistics ... 254
7.9.1 Low Temperatures ... 256
7.9.2 Region of Temperatures ... 256
7.10 Pauli Paramagnetism: Second Difficulty of Classical Statistics ... 258
7.11 "Ultra-Relativistic" Electron Gas in Semiconductors ... 262
7.12 Statistics of Charge Carriers in Semiconductors ... 265
7.13 Degenerate Bose Gas: Bose–Einstein Condensation ... 277
7.14 Photon Gas: Third Difficulty of Classical Statistics ... 282
7.15 Phonon Gas ... 289

**8 Electron Gas in Quantizing Magnetic Field** ... 297
8.1 Motion of Electron in External Uniform Magnetic Field: Quantization of Energy Spectrum ... 297
8.2 Density of Quantum States in Strong Magnetic Field ... 302

8.3 Grand Thermodynamic Potential and Statistics of Electron Gas in Quantizing Magnetic Field ..... 304
8.4 Thermodynamic Properties of Electron Gas in Quantizing Magnetic Field ..... 310
8.5 Landau Diamagnetism ..... 314

**9 Non-Equilibrium Electron Gas in Solids** ..... 321
9.1 Boltzmann Equation and Its Applicability Conditions ..... 321
9.1.1 Nonequilibrium Distribution Function ..... 321
9.1.2 Boltzmann Equation ..... 323
9.1.3 Applicability Conditions of the Boltzmann Equation ... 325
9.2 Solution of Boltzmann Equation in Relaxation Time Approximation ..... 328
9.2.1 Relaxation Time ..... 328
9.2.2 Solution of the Boltzmann Equation in the Absence of Magnetic Field ..... 330
9.2.3 Solution of Boltzmann Equation with an Arbitrary Nonquantizing Magnetic Field ..... 336
9.3 General Expressions of Main Kinetic Coefficients ..... 340
9.3.1 Current Density and General Form of Conductivity Tensors ..... 340
9.3.2 General Expressions of Main Kinetic Coefficients ..... 342
9.4 Main Relaxation Mechanisms ..... 344
9.4.1 Charge Carrier Scattering by Ionized Impurity Atoms .. 345
9.4.2 Charge Carrier Scattering by Phonons in Conductors with Arbitrary Isotropic Band ..... 348
9.4.3 Generalized Formula for Relaxation Time ..... 357
9.5 Boltzmann Equation Solution for Anisotropic Band in Relaxation Time Tensor Approximation ..... 359
9.5.1 Current Density ..... 359
9.5.2 The Boltzmann Equation Solution ..... 360
9.5.3 Current Density ..... 362

**Definite Integrals Frequently Met in Statistical Physics** ..... 363
A.1 Gamma-Function or Euler Integral of Second Kind ..... 363
A.2 Integral of Type ..... 364
A.3 Integral of Type ..... 365
A.4 Integral of Type ..... 366
A.5 Integral of Type ..... 367

**Jacobian and Its Properties** ..... 369

**Bibliograpy** ..... 371

**Index** ..... 373