Contents

Preface to the First Edition xi

Preface to the Second Edition xiv

Preface to the Third Edition xv

1 Review of Thermodynamics 1

1.1 State Variables and Equations of State 1
1.2 Laws of Thermodynamics 3
1.2.1 First law 3
1.2.2 Second law 5
1.3 Thermodynamic Potentials 9
1.4 Gibbs–Duhem and Maxwell Relations 12
1.5 Response Functions 14
1.6 Conditions for Equilibrium and Stability 16
1.7 Magnetic Work 18
1.8 Thermodynamics of Phase Transitions 20
1.9 Problems 24

2 Statistical Ensembles 29

2.1 Isolated Systems: Microcanonical Ensemble 30
2.2 Systems at Fixed Temperature: Canonical Ensemble 35
2.3 Grand Canonical Ensemble 40
2.4 Quantum Statistics 43
2.4.1 Harmonic oscillator 44
2.4.2 Noninteracting fermions 44
2.4.3 Noninteracting bosons 45
2.4.4 Density matrix 46

2.5 Maximum Entropy Principle 48
2.6 Thermodynamic Variational Principles 53
2.6.1 Schottky defects in a crystal 53
2.7 Problems 54

3 Mean Field and Landau Theory **63**
3.1 Mean Field Theory of the Ising Model 64
3.2 Bragg–Williams Approximation 67
3.3 A Word of Warning 69
3.4 Bethe Approximation 71
3.5 Critical Behavior of Mean Field Theories 74
3.6 Ising Chain: Exact Solution 77
3.7 Landau Theory of Phase Transitions 83
3.8 Symmetry Considerations 86
3.8.1 Potts model 87
3.9 Landau Theory of Tricritical Points 90
3.10 Landau–Ginzburg Theory for Fluctuations 94
3.11 Multicomponent Order Parameters: n-Vector Model 98
3.12 Problems 100

4 Applications of Mean Field Theory **109**
4.1 Order–Disorder Transition 110
4.2 Maier–Saupe Model 114
4.3 Blume–Emery–Griffiths Model 120
4.4 Mean Field Theory of Fluids: van der Waals Approach 123
4.5 Spruce Budworm Model 129
4.6 A Non-Equilibrium System: Two Species Asymmetric Exclusion Model 132
4.7 Problems 137

5 Dense Gases and Liquids **143**
5.1 Virial Expansion 145
5.2 Distribution Functions 151
5.2.1 Pair correlation function 151
5.2.2 BBGKY hierarchy 157
5.2.3 Ornstein–Zernike equation 158
5.3 Perturbation Theory 161
5.4 Inhomogeneous Liquids 163
5.4.1 Liquid–vapor interface 164

5.4.2 Capillary waves 169
5.5 Density-Functional Theory 171
5.5.1 Functional differentiation 171
5.5.2 Free-energy functionals and correlation functions 174
5.5.3 Applications 179
5.6 Problems 181

6 Critical Phenomena I **183**
6.1 Ising Model in Two Dimensions 184
6.1.1 Transfer matrix 184
6.1.2 Transformation to an interacting fermion problem . . . 188
6.1.3 Calculation of eigenvalues 191
6.1.4 Thermodynamic functions 194
6.1.5 Concluding remarks 199
6.2 Series Expansions 199
6.2.1 High-temperature expansions 200
6.2.2 Low-temperature expansions 206
6.2.3 Analysis of series 206
6.3 Scaling 211
6.3.1 Thermodynamic considerations 211
6.3.2 Scaling hypothesis 212
6.3.3 Kadanoff block spins 215
6.4 Finite-Size Scaling 218
6.5 Universality 223
6.6 Kosterlitz–Thouless Transition 226
6.7 Problems 233

7 Critical Phenomena II: The Renormalization Group **237**
7.1 The Ising Chain Revisited 238
7.2 Fixed Points 242
7.3 An Exactly Solvable Model: Ising Spins on a Diamond Fractal 248
7.4 Position Space Renormalization: Cumulant Method 258
7.4.1 First-order approximation 262
7.4.2 Second-order approximation 264
7.5 Other Position Space Renormalization Group Methods 267
7.5.1 Finite lattice methods 267
7.5.2 Adsorbed monolayers: Ising antiferromagnet 268
7.5.3 Monte Carlo renormalization 272

7.6 Phenomenological Renormalization Group 275
7.7 The ϵ-Expansion 279
7.7.1 The Gaussian model 281
7.7.2 The S^4 model 284
7.7.3 Conclusion 290
Appendix: Second Order Cumulant Expansion 292
7.8 Problems 295

8 Stochastic Processes **303**
8.1 Markov Processes and the Master Equation 304
8.2 Birth and Death Processes 306
8.3 Branching Processes 309
8.4 Fokker–Planck Equation 313
8.5 Fokker–Planck Equation with Several Variables: SIR Model . . 316
8.6 Jump Moments for Continuous Variables 321
8.6.1 Brownian motion 323
8.6.2 Rayleigh and Kramers equations 326
8.7 Diffusion, First Passage and Escape 328
8.7.1 Natural boundaries: The Kimura–Weiss model for genetic drift 329
8.7.2 Artificial boundaries 331
8.7.3 First passage time and escape probability 332
8.7.4 Kramers escape rate 337
8.8 Transformations of the Fokker–Planck Equation 340
8.8.1 Heterogeneous diffusion 340
8.8.2 Transformation to the Schrödinger equation 343
8.9 Problems 345

9 Simulations **349**
9.1 Molecular Dynamics 350
9.1.1 Conservative molecular dynamics 351
9.1.2 Brownian dynamics 353
9.1.3 Data analysis 355
9.2 Monte Carlo Method 357
9.2.1 Discrete time Markov processes 358
9.2.2 Detailed balance and the Metropolis algorithm 359
9.2.3 Histogram methods 363
9.3 Data Analysis 365
9.3.1 Fluctuations 365

9.3.2 Error estimates . . . 367
9.3.3 Extrapolation to the thermodynamic limit . . . 368
9.4 The Hopfield Model of Neural Nets . . . 371
9.5 Simulated Quenching and Annealing . . . 376
9.6 Problems . . . 379

10 Polymers and Membranes **383**
10.1 Linear Polymers . . . 384
10.1.1 The freely jointed chain . . . 386
10.1.2 The Gaussian chain . . . 389
10.2 Excluded Volume Effects: Flory Theory . . . 391
10.3 Polymers and the n-Vector Model . . . 395
10.4 Dense Polymer Solutions . . . 400
10.5 Membranes . . . 405
10.5.1 Phantom membranes . . . 406
10.5.2 Self-avoiding membranes . . . 409
10.5.3 Liquid membranes . . . 415
10.6 Problems . . . 418

11 Quantum Fluids **421**
11.1 Bose Condensation . . . 422
11.2 Superfluidity . . . 430
11.2.1 Qualitative features of superfluidity . . . 430
11.2.2 Bogoliubov theory of the ^{4}He excitation spectrum . . . 439
11.3 Superconductivity . . . 442
11.3.1 Cooper problem . . . 443
11.3.2 BCS ground state . . . 445
11.3.3 Finite-temperature BCS theory . . . 449
11.3.4 Landau–Ginzburg theory of superconductivity . . . 453
11.4 Problems . . . 456

12 Linear Response Theory **461**
12.1 Exact Results . . . 462
12.1.1 Generalized susceptibility and the structure factor . . . 462
12.1.2 Thermodynamic properties . . . 469
12.1.3 Sum rules and inequalities . . . 470
12.2 Mean Field Response . . . 472
12.2.1 Dielectric function of the electron gas . . . 473
12.2.2 Weakly interacting Bose gas . . . 475

12.2.3 Excitations of the Heisenberg ferromagnet 477
12.2.4 Screening and plasmons 480
12.2.5 Exchange and correlation energy 486
12.2.6 Phonons in metals 487
12.3 Entropy Production, the Kubo Formula, and the Onsager Relations for Transport Coefficients 490
12.3.1 Kubo formula 490
12.3.2 Entropy production and generalized currents and forces 492
12.3.3 Microscopic reversibility: Onsager relations 494
12.4 The Boltzmann Equation 498
12.4.1 Fields, drift and collisions 498
12.4.2 DC conductivity of a metal 500
12.4.3 Thermal conductivity and thermoelectric effects 503
12.5 Problems 507

13 Disordered Systems **513**
13.1 Single-Particle States in Disordered Systems 515
13.1.1 Electron states in one dimension 516
13.1.2 Transfer matrix 517
13.1.3 Localization in three dimensions 523
13.1.4 Density of states 525
13.2 Percolation 530
13.2.1 Scaling theory of percolation 533
13.2.2 Series expansions and renormalization group 536
13.2.3 Rigidity percolation 540
13.2.4 Conclusion 542
13.3 Phase Transitions in Disordered Materials 542
13.3.1 Statistical formalism and the replica trick 544
13.3.2 Nature of phase transitions 546
13.4 Strongly Disordered Systems 551
13.4.1 Molecular glasses 552
13.4.2 Spin glasses 554
13.4.3 Sherrington–Kirkpatrick model 558
13.5 Problems 565

A Occupation Number Representation **569**

Bibliography **583**

Index **603**