

# Contents

<b>Preface to the First Edition</b>	<b>xi</b>
<b>Preface to the Second Edition</b>	<b>xiv</b>
<b>Preface to the Third Edition</b>	<b>xv</b>
<b>1 Review of Thermodynamics</b>	<b>1</b>
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
<b>2 Statistical Ensembles</b>	<b>29</b>
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
<b>3</b>	<b>Mean Field and Landau Theory</b>	<b>63</b>
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
<b>4</b>	<b>Applications of Mean Field Theory</b>	<b>109</b>
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
<b>5</b>	<b>Dense Gases and Liquids</b>	<b>143</b>
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
<b>6</b>	<b>Critical Phenomena I</b>	<b>183</b>
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
<b>7</b>	<b>Critical Phenomena II: The Renormalization Group</b>	<b>237</b>
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 $\epsilon$ -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
<b>8</b>	<b>Stochastic Processes</b>	<b>303</b>
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
<b>9</b>	<b>Simulations</b>	<b>349</b>
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
<b>10</b>	<b>Polymers and Membranes</b>	<b>383</b>
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
<b>11</b>	<b>Quantum Fluids</b>	<b>421</b>
11.1	Bose Condensation . . . . .	422
11.2	Superfluidity . . . . .	430
11.2.1	Qualitative features of superfluidity . . . . .	430
11.2.2	Bogoliubov theory of the $^4\text{He}$ 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
<b>12</b>	<b>Linear Response Theory</b>	<b>461</b>
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
<b>13</b>	<b>Disordered Systems</b>	<b>513</b>
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
<b>A</b>	<b>Occupation Number Representation</b>	<b>569</b>
	<b>Bibliography</b>	<b>583</b>
	<b>Index</b>	<b>603</b>