

Contents

<i>Preface to the Second Edition</i>	<i>page</i> xiii
<i>Acknowledgments</i>	xv
<i>Notations</i>	xvi
<i>List of Abbreviations</i>	xvii
1 Kinetic Theory and the Boltzmann Equation	1
1.1 Historical Perspective	2
1.2 Kinetic Theory	4
1.2.1 The Ideal Gas	4
1.2.2 Transport Phenomena	7
1.3 Distribution Function in Molecular Space	10
1.4 Time Evolution of the Distribution Function	12
1.5 The H-theorem in the Spatially Uniform Case	18
1.6 The H-theorem in the Nonuniform Case	22
1.7 Evolution toward Equilibrium and Transport Phenomena	27
1.7.1 Additive Invariants	29
1.7.2 Hydrodynamics of the Inviscid Flow	32
1.7.3 Hydrodynamics: First-order Approximation	34
1.8 Bibliographic Notes	38
2 Brownian Motion, Langevin, and Fokker–Planck Equations	39
2.1 The Origins of Stochastic Processes	40
2.2 Brownian Motion	41
2.2.1 Random Walk: A Basic Model of Diffusion	44
2.2.2 The Langevin Equation for the Brownian Particle	47
2.2.3 The Fokker–Planck Equation for the Brownian Particle	50
2.3 Discrete Time Stochastic Processes	52
2.3.1 Markov Chains	52
2.3.2 Basic Examples of Markov Chains	55
2.3.3 Random Walk with Absorbing Barriers	58
2.3.4 Ergodic Markov Chains	61
2.3.5 Master Equation and Detailed Balance	63
2.3.6 Monte Carlo Method	64
2.4 Continuous Time Stochastic Processes	66
2.4.1 Continuous Time Master Equation	67
2.4.2 Equilibrium States versus Stationary States	68

2.4.3	Stochastic Differential Equations	70
2.4.4	The Langevin Equation and Detailed Balance	74
2.4.5	General Fokker–Planck Equation	76
2.4.6	Physical Applications of the Fokker–Planck Equation	78
2.5	A Different Pathway to the Fokker–Planck Equation	83
2.5.1	First Exit Time and the Arrhenius Formula	86
2.6	Bibliographic Notes	90
3	Fluctuations and Their Probability	91
3.1	Links between Statistics and Physics	92
3.2	The Central Limit Theorem	94
3.3	Large Deviations	97
3.3.1	The Bimodal Distribution	98
3.3.2	The Exponential Distribution	99
3.3.3	The Cramer Function	100
3.3.4	Power Law Distributions	102
3.3.5	Extreme Value Statistics	103
3.4	Random Matrices	104
3.5	Generalized Random Walks	106
3.5.1	Continuous Time Random Walk	107
3.5.2	Lévy Walks	115
3.5.3	Anomalous Diffusion: A Summary	118
3.6	Statistical Fluctuations between Equilibrium and Out-of-equilibrium	119
3.7	Einstein’s Approach	121
3.8	Stochastic Thermodynamics: An Introduction	126
3.8.1	Jarzynski Equality	127
3.8.2	Crooks Fluctuation Theorem	130
3.8.3	Fluctuation Theorem for a NESS	135
3.9	Bibliographic Notes	140
4	Linear Response Theory and Transport Phenomena	141
4.1	A Theoretical Basis for Transport Processes	142
4.2	The Kubo Formula for the Brownian Particle	144
4.3	Generalized Brownian Motion	146
4.4	Linear Response to an External Force	148
4.4.1	Linear Response and Fluctuation–Dissipation Relation	150
4.4.2	Work Done by a Time-Dependent Field	154
4.4.3	Simple Applications of Linear Response Theory	155
4.5	Hydrodynamics and the Green–Kubo Relation	160
4.6	Generalized Linear Response Function	165
4.6.1	Onsager Regression Relation and Time Reversal	167
4.7	Entropy Production, Fluxes, and Thermodynamic Forces	169
4.7.1	Nonequilibrium Conditions between Macroscopic Systems	169
4.7.2	Phenomenological Equations	172

4.7.3	Variational Principle	175
4.7.4	Nonequilibrium Conditions in a Continuous System	177
4.8	Physical Applications of Onsager Reciprocity Relations	180
4.8.1	Coupled Transport of Neutral Particles	180
4.8.2	Onsager Theorem and Transport of Charged Particles	184
4.9	Bibliographic Notes	196
5 From Equilibrium to Out-of-Equilibrium Phase Transitions:		
	Driven Lattice Gases	198
5.1	The Importance of Phase Transitions	199
5.2	Basic Concepts and Tools of Equilibrium Phase Transitions	200
5.2.1	Phase Transitions and Thermodynamics	200
5.2.2	Phase Transitions and Statistical Mechanics	203
5.2.3	Landau Theory of Critical Phenomena	206
5.2.4	Critical Exponents and Scaling Hypothesis	211
5.2.5	Phenomenological Scaling Theory	214
5.2.6	Scale Invariance and Renormalization Group	216
5.2.7	Equilibrium Phase Transitions Do Not Generally Exist in One Dimension	221
5.3	The Model of Katz, Lebowitz, and Spohn	222
5.4	The (T)ASEP Models	224
5.4.1	ASEP with Periodic Boundary Conditions	225
5.4.2	TASEP with Open Boundary Conditions	227
5.5	Symmetry Breaking: The Bridge Model	231
5.5.1	Mean-Field Solution	233
5.5.2	Exact Solution for $\beta \ll 1$	235
5.6	Bibliographic Notes	240
6 Absorbing Phase Transitions		
6.1	From Isotropic to Directed Percolation	242
6.2	The Domany–Kinzel Model of Cellular Automata	245
6.2.1	Contact Processes	249
6.3	The Phase Transition in DP-Like Systems	250
6.3.1	Control Parameters, Order Parameters, and Critical Exponents	250
6.3.2	Phenomenological Scaling Theory	254
6.3.3	Mean-Field Theory	256
6.4	Beyond the DP Universality Class	259
6.4.1	More Absorbing States	259
6.4.2	Conservation Laws	263
6.5	Self-Organized Critical Models	264
6.5.1	The Bak–Tang–Wiesenfeld Model	267
6.6	Bibliographic Notes	269

7 Stochastic Dynamics of Surfaces and Interfaces	271
7.1 The Physics of Growth Processes	272
7.2 Roughness: Definition, Scaling, and Exponents	274
7.3 Deposition Models	278
7.3.1 The Random Deposition Model	278
7.3.2 Random Deposition with Relaxation	279
7.3.3 Deposition without Conservation	281
7.4 Self-Similarity and Self-Affinity	283
7.5 Symmetries and Power Counting: Toward Langevin-Type Equations	285
7.6 The Edwards–Wilkinson Equation	290
7.6.1 Dimensional Analysis	292
7.6.2 The Scaling Functions	294
7.7 The Kardar–Parisi–Zhang Equation	299
7.7.1 Overview of KPZ versus Dimension d	299
7.7.2 The Galilean (or Tilt) Transformation	301
7.7.3 Exact Exponents in $d = 1$	305
7.7.4 Beyond the Exponents	308
7.7.5 Experimental Results	310
7.8 Nonlocal Models	312
7.9 Bibliographic Notes	317
8 Phase-Ordering Kinetics	319
8.1 The Equilibrium Phase Diagrams	320
8.2 Quenching and Relaxation to Equilibrium	325
8.2.1 The Langevin Approach	328
8.3 The Correlation Function and the Structure Factor	333
8.4 The Coarsening Law in Ising-Like Systems: Nonconserved Dynamics	338
8.4.1 The Continuum Picture in Any Dimension	338
8.4.2 The Discrete Picture in $d = 1$	342
8.5 The Coarsening Law in Ising-Like Systems: Conserved Dynamics	346
8.5.1 The Continuum Picture in $d > 1$	346
8.5.2 The Discrete Picture in $d = 1$	350
8.6 Domain Size Distribution	352
8.7 The Coarsening Law in Nonscalar Systems	354
8.8 The Classical Nucleation Theory	362
8.8.1 The Becker–Döring Theory	364
8.9 Bibliographic Notes	369
9 Highlights on Pattern Formation	370
9.1 Pattern Formation in the Laboratory and the Real World	370
9.2 Linear Stability Analysis and Bifurcation Scenarios	374
9.3 The Turing Instability	380
9.3.1 Linear Stability Analysis	381
9.3.2 The Brusselator Model	385

9.4	Periodic Steady States	387
9.5	Energetics	393
9.6	Nonlinear Dynamics for Pattern-Forming Systems: The Envelope Equation	395
9.7	The Eckhaus Instability	399
9.8	Phase Dynamics	403
9.9	Back to Experiments	406
9.10	Bibliographic Notes	408
Appendix A Binary Elastic Collisions in the Hard Sphere Gas		410
Appendix B Maxwell–Boltzmann Distribution in the Uniform Case		414
Appendix C Physical Quantities from the Boltzmann Equation in the Nonuniform Case		416
Appendix D Outline of the Chapman–Enskog Method		420
Appendix E First-order Approximation to Hydrodynamics		424
Appendix F Spectral Properties of Stochastic Matrices		427
Appendix G Reversibility and Ergodicity in a Markov Chain		429
Appendix H The Ising Model		431
Appendix I The Deterministic KPZ Equation and the Burgers Equation		440
Appendix J Stochastic Differential Equation for the Energy of the Brownian Particle		446
Appendix K The Kramers–Moyal Expansion		448
Appendix L Probability Distributions		450
Appendix M The Diffusion Equation and the Random Walk		452
Appendix N Linear Response in Quantum Systems		460
Appendix O Mathematical Properties of Response Functions		469
Appendix P The Van der Waals Equation		473
Appendix Q Derivation of the Ginzburg–Landau Free Energy		477

Appendix R	The Perturbative Renormalization Group for KPZ	480
Appendix S	TASEP: Map Method and Simulations	484
Appendix T	Bridge Model: Mean-field and Simulations	489
Appendix U	The Allen–Cahn Equation	494
Appendix V	The Gibbs–Thomson Relation	496
Appendix W	The Rayleigh–Bénard Instability	498
Appendix X	General Conditions for the Turing Instability	504
Appendix Y	Steady States of the One-Dimensional TDGL Equation	506
Appendix Z	Multiscale Analysis	507
	<i>Index</i>	510