



# Contents

Preface to the Third Edition	xiii
Preface to the Second Edition	xvii
Preface to the First Edition	xix
Historical Introduction	xxi
<b>1. The Statistical Basis of Thermodynamics</b>	<b>1</b>
1.1. The macroscopic and the microscopic states	1
1.2. Contact between statistics and thermodynamics: physical significance of the number $\Omega(N, V, E)$	3
1.3. Further contact between statistics and thermodynamics	6
1.4. The classical ideal gas	9
1.5. The entropy of mixing and the Gibbs paradox	16
1.6. The “correct” enumeration of the microstates	20
Problems	22
<b>2. Elements of Ensemble Theory</b>	<b>25</b>
2.1. Phase space of a classical system	25
2.2. Liouville’s theorem and its consequences	27
2.3. The microcanonical ensemble	30
2.4. Examples	32
2.5. Quantum states and the phase space	35
Problems	37

<b>3.</b>	<b>The Canonical Ensemble</b>	<b>39</b>
3.1.	Equilibrium between a system and a heat reservoir	40
3.2.	A system in the canonical ensemble	41
3.3.	Physical significance of the various statistical quantities in the canonical ensemble	50
3.4.	Alternative expressions for the partition function	52
3.5.	The classical systems	54
3.6.	Energy fluctuations in the canonical ensemble: correspondence with the microcanonical ensemble	58
3.7.	Two theorems — the “equipartition” and the “virial”	61
3.8.	A system of harmonic oscillators	65
3.9.	The statistics of paramagnetism	70
3.10.	Thermodynamics of magnetic systems: negative temperatures	77
	Problems	83
<b>4.</b>	<b>The Grand Canonical Ensemble</b>	<b>91</b>
4.1.	Equilibrium between a system and a particle-energy reservoir	91
4.2.	A system in the grand canonical ensemble	93
4.3.	Physical significance of the various statistical quantities	95
4.4.	Examples	98
4.5.	Density and energy fluctuations in the grand canonical ensemble: correspondence with other ensembles	103
4.6.	Thermodynamic phase diagrams	105
4.7.	Phase equilibrium and the Clausius–Clapeyron equation	109
	Problems	111
<b>5.</b>	<b>Formulation of Quantum Statistics</b>	<b>115</b>
5.1.	Quantum-mechanical ensemble theory: the density matrix	115
5.2.	Statistics of the various ensembles	119

5.3. Examples	122
5.4. Systems composed of indistinguishable particles	128
5.5. The density matrix and the partition function of a system of free particles	133
Problems	139
<b>6. The Theory of Simple Gases</b>	<b>141</b>
6.1. An ideal gas in a quantum-mechanical microcanonical ensemble	141
6.2. An ideal gas in other quantum-mechanical ensembles	146
6.3. Statistics of the occupation numbers	149
6.4. Kinetic considerations	152
6.5. Gaseous systems composed of molecules with internal motion	155
6.6. Chemical equilibrium	170
Problems	173
<b>7. Ideal Bose Systems</b>	<b>179</b>
7.1. Thermodynamic behavior of an ideal Bose gas	180
7.2. Bose-Einstein condensation in ultracold atomic gases	191
7.3. Thermodynamics of the blackbody radiation	200
7.4. The field of sound waves	205
7.5. Inertial density of the sound field	212
7.6. Elementary excitations in liquid helium II	215
Problems	223
<b>8. Ideal Fermi Systems</b>	<b>231</b>
8.1. Thermodynamic behavior of an ideal Fermi gas	231
8.2. Magnetic behavior of an ideal Fermi gas	238
8.3. The electron gas in metals	247
8.4. Ultracold atomic Fermi gases	258

8.5.	Statistical equilibrium of white dwarf stars	259
8.6.	Statistical model of the atom	264
	Problems	269
<b>9.</b>	<b>Thermodynamics of the Early Universe</b>	<b>275</b>
9.1.	Observational evidence of the Big Bang	275
9.2.	Evolution of the temperature of the universe	280
9.3.	Relativistic electrons, positrons, and neutrinos	282
9.4.	Neutron fraction	285
9.5.	Annihilation of the positrons and electrons	287
9.6.	Neutrino temperature	289
9.7.	Primordial nucleosynthesis	290
9.8.	Recombination	293
9.9.	Epilogue	295
	Problems	296
<b>10.</b>	<b>Statistical Mechanics of Interacting Systems: The Method of Cluster Expansions</b>	<b>299</b>
10.1.	Cluster expansion for a classical gas	299
10.2.	Virial expansion of the equation of state	307
10.3.	Evaluation of the virial coefficients	309
10.4.	General remarks on cluster expansions	315
10.5.	Exact treatment of the second virial coefficient	320
10.6.	Cluster expansion for a quantum-mechanical system	325
10.7.	Correlations and scattering	331
	Problems	340
<b>11.</b>	<b>Statistical Mechanics of Interacting Systems: The Method of Quantized Fields</b>	<b>345</b>
11.1.	The formalism of second quantization	345
11.2.	Low-temperature behavior of an imperfect Bose gas	355

11.3.	Low-lying states of an imperfect Bose gas	361
11.4.	Energy spectrum of a Bose liquid	366
11.5.	States with quantized circulation	370
11.6.	Quantized vortex rings and the breakdown of superfluidity	376
11.7.	Low-lying states of an imperfect Fermi gas	379
11.8.	Energy spectrum of a Fermi liquid: Landau's phenomenological theory	385
11.9.	Condensation in Fermi systems	392
	Problems	394
<b>12.</b>	<b>Phase Transitions: Criticality, Universality, and Scaling</b>	<b>401</b>
12.1.	General remarks on the problem of condensation	402
12.2.	Condensation of a van der Waals gas	407
12.3.	A dynamical model of phase transitions	411
12.4.	The lattice gas and the binary alloy	417
12.5.	Ising model in the zeroth approximation	420
12.6.	Ising model in the first approximation	427
12.7.	The critical exponents	435
12.8.	Thermodynamic inequalities	438
12.9.	Landau's phenomenological theory	442
12.10.	Scaling hypothesis for thermodynamic functions	446
12.11.	The role of correlations and fluctuations	449
12.12.	The critical exponents $\nu$ and $\eta$	456
12.13.	A final look at the mean field theory	460
	Problems	463
<b>13.</b>	<b>Phase Transitions: Exact (or Almost Exact) Results for Various Models</b>	<b>471</b>
13.1.	One-dimensional fluid models	471
13.2.	The Ising model in one dimension	476

13.3.	The $n$ -vector models in one dimension	482
13.4.	The Ising model in two dimensions	488
13.5.	The spherical model in arbitrary dimensions	508
13.6.	The ideal Bose gas in arbitrary dimensions	519
13.7.	Other models	526
	Problems	530
<b>14.</b>	<b>Phase Transitions: The Renormalization Group Approach</b>	<b>539</b>
14.1.	The conceptual basis of scaling	540
14.2.	Some simple examples of renormalization	543
14.3.	The renormalization group: general formulation	552
14.4.	Applications of the renormalization group	559
14.5.	Finite-size scaling	570
	Problems	579
<b>15.</b>	<b>Fluctuations and Nonequilibrium Statistical Mechanics</b>	<b>583</b>
15.1.	Equilibrium thermodynamic fluctuations	584
15.2.	The Einstein–Smoluchowski theory of the Brownian motion	587
15.3.	The Langevin theory of the Brownian motion	593
15.4.	Approach to equilibrium: the Fokker–Planck equation	603
15.5.	Spectral analysis of fluctuations: the Wiener–Khintchine theorem	609
15.6.	The fluctuation–dissipation theorem	617
15.7.	The Onsager relations	626
	Problems	632
<b>16.</b>	<b>Computer Simulations</b>	<b>637</b>
16.1.	Introduction and statistics	637
16.2.	Monte Carlo simulations	640
16.3.	Molecular dynamics	643
16.4.	Particle simulations	646

16.5. Computer simulation caveats	650
Problems	651
Appendices	653
A. Influence of boundary conditions on the distribution of quantum states	653
B. Certain mathematical functions	655
C. “Volume” and “surface area” of an $n$ -dimensional sphere of radius $R$	662
D. On Bose–Einstein functions	664
E. On Fermi–Dirac functions	667
F. A rigorous analysis of the ideal Bose gas and the onset of Bose–Einstein condensation	670
G. On Watson functions	675
H. Thermodynamic relationships	676
I. Pseudorandom numbers	683
Bibliography	687
Index	707