

Contents

| | |
|----------------------------------|------|
| <i>Preface</i> | ix |
| <i>List of Symbols</i> | xiii |

I MASS POINT GAS

| | |
|---|----|
| 1.1 Introduction | 1 |
| 1.2 Uniform Space Distributions | 1 |
| 1.3 Nonuniform Space Distributions | 3 |
| 1.4 Average or Expected Value of Observable Quantities | 4 |
| 1.5 Average or Expected Free Paths | 6 |
| 1.6 Mass Point Gas | 8 |
| 1.7 Effusive Flow of a Mass Point Gas | 10 |
| 1.8 Pressure of a Mass Point Gas | 12 |
| 1.9 Speed Distribution Function | 15 |
| 1.10 Momentum Transfer and Heat Transfer in Free Molecular Flow | 22 |
| 1.11 Free Molecular Flow | 25 |
| References | 35 |

II RADIATION

| | |
|--|----|
| 2.1 Introduction | 36 |
| 2.2 Electromagnetic Radiation | 37 |
| 2.3 Thermal Radiation | 43 |
| 2.4 Surface Absorption and Emission of Thermal Radiation | 45 |
| 2.5 Radiation Pressure | 48 |
| 2.6 Experimental Verification of the Frequency Distribution of Thermal Radiation | 51 |
| 2.7 Radiation Temperature | 56 |
| 2.8 Interaction of Radiation with an Atom | 58 |
| 2.9 Thermal Radiation in Enclosures Containing Matter | 64 |
| 2.10 Absorption and Emission of Radiation by Matter | 65 |
| 2.11 Motion through Thermal Radiation | 69 |
| References | 72 |

III PROBABILITY, STATISTICS, AND CONDITIONAL PROBABILITY

| | |
|--|----|
| 3.1 Introduction | 73 |
| 3.2 Integral-Valued Random Variables | 73 |
| 3.3 Useful Mathematical Formulas | 78 |
| 3.4 Random Walk | 79 |
| 3.5 Binomial and Poisson Distributions | 84 |
| 3.6 Central Limit Theorem | 87 |

| | | |
|------|---|-----|
| 3.7 | Conditional Probability | 89 |
| 3.8 | Physical Processes Continuous in Space and Time | 98 |
| 3.9 | Random Walk with Absorbing Boundaries | 104 |
| 3.10 | Some Probability Laws Frequently Encountered in Physics | 109 |
| | References | 112 |
| | General References | 112 |

IV INTERMOLECULAR INTERACTIONS

| | | |
|-----|--|-----|
| 4.1 | Introduction | 113 |
| 4.2 | Classical Elastic Collisions | 115 |
| 4.3 | Quantum Aspects of Elastic Collisions | 120 |
| 4.4 | Cross Sections for Diffusion and Viscosity | 131 |
| 4.5 | Elastic and Inelastic Binary Collisions | 135 |
| 4.6 | Inelastic Scattering Cross Section | 153 |
| 4.7 | Atomic Cross Sections from Atomic Beam Experiments | 163 |
| 4.8 | Interaction of Molecules with Solid Surfaces | 166 |
| | References | 173 |

V TRANSPORT PHENOMENA

| | | |
|-----|--|-----|
| 5.1 | Introduction | 175 |
| 5.2 | Elementary Theory of Transport | 175 |
| 5.3 | Gas Dynamics | 182 |
| 5.4 | Nonequilibrium Properties of the Distribution Function | 190 |
| 5.5 | General Transport Equations | 194 |
| 5.6 | Equilibrium Mixture of Two Gases | 197 |
| 5.7 | Diffusion | 198 |
| 5.8 | Sound Waves in Gases | 200 |
| | References | 204 |

VI STATISTICAL THERMODYNAMICS

| | | |
|-----|-----------------------------------|-----|
| 6.1 | Introduction | 205 |
| 6.2 | Laws of Thermodynamics | 205 |
| 6.3 | Thermodynamic Functions | 214 |
| 6.4 | Statistical Physics | 218 |
| | References | 228 |
| | General References | 228 |

VII MOLECULAR SYSTEMS AT LOW DENSITIES

| | | |
|-----|--|-----|
| 7.1 | Nearly Ideal Gases | 230 |
| 7.2 | Photon Gas | 234 |
| 7.3 | Bose and Fermi Distributions | 236 |

| | | |
|------|--|-----|
| 7.4 | Chemical Reactions | 240 |
| 7.5 | Thermal Ionization and Excitation of Atoms | 240 |
| 7.6 | Thermodynamic Properties of Heteronuclear Diatomic Molecules | 247 |
| 7.7 | Homonuclear Diatomic Molecules | 252 |
| 7.8 | Equipartition Theorem | 256 |
| 7.9 | Gases at Very High Temperatures | 261 |
| 7.10 | Paramagnetism | 266 |
| | References | 277 |

VIII NONIDEAL AND REAL GASES

| | | |
|-----|--|-----|
| 8.1 | Nonideal Gases | 279 |
| 8.2 | Cluster Expansion | 279 |
| 8.3 | Equation of State and Second Virial Coefficient | 281 |
| 8.4 | Second Virial Coefficients for Classical, Fermi-Dirac, and Bose-Einstein Gases | 287 |
| 8.5 | Second Virial Coefficient for Molecular Gases with Interaction | 291 |
| 8.6 | Intermolecular Potentials | 301 |
| 8.7 | Degenerate Fermi-Dirac Gas—Electrons in Metals and in Very Dense Matter | 305 |
| 8.8 | Degenerate Bose-Einstein Gas | 318 |
| | References | 323 |

IX GASES, LIQUIDS, AND SOLIDS

| | | |
|-----|--|-----|
| 9.1 | Introduction | 325 |
| 9.2 | Thermodynamic Aspects of Equilibrium between Phases | 326 |
| 9.3 | Phonon Gas | 333 |
| 9.4 | Thermodynamic Systems that Are Composed of Different Particles | 341 |
| 9.5 | The Third Law of Thermodynamics | 345 |
| 9.6 | Binary Mixtures | 355 |
| 9.7 | A Combinatorial Problem | 372 |
| 9.8 | Experimental Critical Points | 397 |
| 9.9 | Surface-Gas-Phase Equilibrium | 402 |
| | References | 410 |

X STOCHASTIC PROCESSES, NOISE, AND FLUCTUATIONS

| | | |
|------|---|-----|
| 10.1 | Introduction | 413 |
| 10.2 | Thermal Motion of a One-Dimensional System | 414 |
| 10.3 | Random Pulses | 419 |
| 10.4 | Correlation Function and Spectral Density | 423 |
| 10.5 | Response of a Simple Harmonic Oscillator to Random Pulses and Thermal Noise | 427 |
| 10.6 | Correlation Function and Spectral Density for Brownian Motion | 433 |
| 10.7 | Response of Electrical Circuits to Random Pulses and Thermal Noise | 435 |

| | | |
|-------|--|-----|
| 10.8 | Fluctuation Dissipation Theorem | 440 |
| 10.9 | Fluctuations in Thermal Radiation | 442 |
| 10.10 | General Theory of Fluctuations in Statistical Thermodynamics | 444 |
| 10.11 | Correlation of Fluctuations and Measurement with Waves | 450 |
| 10.12 | Nonlinear Physical Systems | 469 |
| 10.13 | Characteristic Functions for Random Pulses | 478 |
| 10.14 | Random Processes | 482 |
| | References | 491 |

XI STOCHASTIC PROCESSES IN QUANTUM SYSTEMS

| | | |
|------|---|-----|
| 11.1 | Introduction | 493 |
| 11.2 | Elementary Theory of Transition Rates | 494 |
| 11.3 | Density Matrix and the Response of Atoms and Molecules to Perturbations | 497 |
| 11.4 | Natural Line Width | 513 |
| 11.5 | Recoilless Emission and the Mössbauer Effect | 518 |
| 11.6 | Damping and the Golden Rule for Transition Rates | 526 |
| 11.7 | Theory for Broadening of Spectral Lines in Gases | 534 |
| 11.8 | Scattering by Crystals, Liquids, and High-Pressure Gases | 548 |
| | References | 586 |

| | | |
|--|-----------------------------------|-----|
| | Appendix A: FUNDAMENTAL CONSTANTS | 589 |
|--|-----------------------------------|-----|

| | | |
|--|--------------------------------|-----|
| | Appendix B: GAUSSIAN INTEGRALS | 590 |
|--|--------------------------------|-----|

| | | |
|------------------------|--|-----|
| <i>Index</i> | | 591 |
|------------------------|--|-----|