Contents

CHAPTER I INTRODUCTORY KINETIC THEORY 1

1 Introduction, 1
2 Molecular Model, 2
3 Pressure, Temperature, and Internal Energy, 4
4 Mean Free Path, 12
5 Transport Phenomena, 15
6 Molecular Magnitudes, 23

CHAPTER II EQUILIBRIUM KINETIC THEORY 27

1 Introduction, 27
2 Velocity Distribution Function, 27
3 Equation of State for a Perfect Gas, 31
4 Maxwellian Distribution—Condition for Equilibrium, 35
5 Maxwellian Distribution—Final Results, 42
6 Collision Rate and Mean Free Path, 48
7 Chemical Equilibrium and the Law of Mass Action, 55

CHAPTER III CHEMICAL THERMODYNAMICS 59

1 Introduction, 59
2 Thermodynamic Systems and Kinds of Equilibrium, 60
3 Conservation of Mass, 63
4 Conservation of Energy; First Law, 65
5 The Second Law, 66
6 The Gibbs Equation for a Chemically Reacting System, 70
7 Entropy Production in Chemical Nonequilibrium; Condition for Reaction Equilibrium, 75
8 Mixtures of Perfect Gases, 77
9 Law of Mass Action, 82
10 Heat of Reaction; van't Hoff's Equation, 83

IV STATISTICAL MECHANICS 86

Introduction, 86
Macroscopic and Microscopic Descriptions, 88
Quantum Energy States, 89
Enumeration of Microstates, 93
Distribution over Energy States—General Case, 101
Distribution over Energy States—Limiting Case, 104
Relation to Thermodynamics; Boltzmann's Relation, 112
Thermodynamic Properties, 117
Properties Associated with Translational Energy, 120
Contribution of Internal Structure, 126
Monatomic Gases, 129
Diatomic Gases, 132
Chemically Reacting Systems and Law of Mass Action, 139
Dissociation-Recombination of Symmetrical Diatomic Gas, 148

V EQUILIBRIUM GAS PROPERTIES 152

Introduction, 152
Symmetrical Diatomic Gas, 152
Ideal Dissociating Gas, 157
Ionization Equilibrium; The Saha Equation, 162
Mixture of Gases, 165
Properties of Equilibrium Air, 171

VI EQUILIBRIUM FLOW 178

Introduction, 178
Steady Shock Waves, 179
Steady Nozzle Flow, 183
Prandtl-Meyer Flow, 187
Frozen Flow, 191

VII VIBRATIONAL AND CHEMICAL RATE PROCESSES 197

Introduction, 197
Vibrational Rate Equation, 198
Entropy Production by Vibrational Nonequilibrium, 206
Chemical Rate Equations—General Considerations, 210
Energy Involved in Collisions, 216
6 Rate Equation for Dissociation-Recombin 222
7 Rate Equation for Complex Mixtures, 228
8 High-Temperature Air, 229
9 Symmetrical Diatomic Gas; Ideal Dissoci
10 Generalized Rate Equation, 234
11 Local Relaxation Time; Small Departu librium, 236

CHAPTER VIII FLOW WITH VIBRATIONAL OR CHEMIC NONEQUILIBRIUM

1 Introduction, 245
2 Basic Nonlinear Equations, 246
3 Equilibrium and Frozen Flow, 251
4 Acoustic Equations, 254
5 Frozen and Equilibrium Speeds of Sound,
6 Propagation of Plane Acoustic Waves, 26
7 Equation for Small Departures from Stream, 269
8 Flow over a Wavy Wall, 274
9 Linearized Flow behind a Normal Shock
10 Equations for Steady Quasi-One-Dimensi
11 Nonlinear Flow behind a Normal Shock
12 Fully Dispersed Shock Wave, 292
13 Nozzle Flow, 293
14 Method of Characteristics, 300
15 Supersonic Flow over a Concave Corner,
16 Supersonic Flow over a Convex Corner,

CHAPTER IX NONEQUILIBRIUM KINETIC THEORY

1 Introduction, 316
2 The Conservation Equations of Gas Dyna
3 The Boltzmann Equation, 328
4 Equilibrium and Entropy, 334
5 The Equations of Equilibrium Flow, 344
6 Moments of the Boltzmann Equation, 346
7 Dynamics of a Binary Collision, 348
8 The Evaluation of Collision Cross-Section
9 The Evaluation of Collision Integrals, 361
10 Gas Mixtures, 368

6 Rate Equation for Dissociation-Recombination Reactions, 222
7 Rate Equation for Complex Mixtures, 228
8 High-Temperature Air, 229
9 Symmetrical Diatomic Gas; Ideal Dissociating Gas, 232
10 Generalized Rate Equation, 234
11 Local Relaxation Time; Small Departures from Equilibrium, 236

CHAPTER VIII FLOW WITH VIBRATIONAL OR CHEMICAL NONEQUILIBRIUM 245

1 Introduction, 245
2 Basic Nonlinear Equations, 246
3 Equilibrium and Frozen Flow, 251
4 Acoustic Equations, 254
5 Frozen and Equilibrium Speeds of Sound, 259
6 Propagation of Plane Acoustic Waves, 261
7 Equation for Small Departures from a Uniform Free Stream, 269
8 Flow over a Wavy Wall, 274
9 Linearized Flow behind a Normal Shock Wave, 281
10 Equations for Steady Quasi-One-Dimensional Flow, 286
11 Nonlinear Flow behind a Normal Shock Wave, 290
12 Fully Dispersed Shock Wave, 292
13 Nozzle Flow, 293
14 Method of Characteristics, 300
15 Supersonic Flow over a Concave Corner, 305
16 Supersonic Flow over a Convex Corner, 310

CHAPTER IX NONEQUILIBRIUM KINETIC THEORY 316

1 Introduction, 316
2 The Conservation Equations of Gas Dynamics, 317
3 The Boltzmann Equation, 328
4 Equilibrium and Entropy, 334
5 The Equations of Equilibrium Flow, 344
6 Moments of the Boltzmann Equation, 346
7 Dynamics of a Binary Collision, 348
8 The Evaluation of Collision Cross-Sections, 356
9 The Evaluation of Collision Integrals, 361
10 Gas Mixtures, 368

X FLOW WITH TRANSLATIONAL NONEQUILIBRIUM 375

ntroduction, 375
he Bhatnagar-Gross-Krook Collision Model, 376
he Chapman-Enskog Solution of the Krook Equation, 379
he Chapman-Enskog Solution of the Boltzmann Equation, 385
he Navier-Stokes Equations, 390
xpansion in Sonine Polynomials, 394
ransport Properties, 403
ulk Viscosity, 407
he Structure of Shock Waves, 412
Linearized Couette Flow, 424

ER XI RADIATIVE TRANSFER IN GASES 436

1 Introduction, 436
2 Energy Transfer by Radiation, 437
3 The Equation of Radiative Transfer, 443
4 Radiative Equilibrium, 446
5 The Interaction of Radiation with Solid Surfaces, 450
6 Emission and Absorption of Radiation, 452
7 Quasi-Equilibrium Hypothesis, 458
8 Formal Solution of the Equation of Radiative Transfer, 462
9 Simplifications and Approximations, 465

TER XII FLOW WITH RADIATIVE NONEQUILIBRIUM 473

1 Introduction, 473
2 Basic Nonlinear Equations, 474
3 Asymptotic Situations; Grey-Gas Approximation, 476
4 One-Dimensional Equations, 479
5 Linearized One-Dimensional Equations, 485
6 Differential Approximation, 491
7 Acoustic Equation, 496
8 Propagation of Plane Acoustic Waves, 499
9 Equation for Small Departures from a Uniform Free Stream, 505
10 Linearized Flow through a Normal Shock Wave, 508
11 Nonlinear Flow through a Normal Shock Wave, 515

APPENDIX

1 Definite Integrals, 523
2 Fundamental Physical Constan
3 Physical Constants for Constitu

SUBJECT INDEX

SYMBOL INDEX

APPENDIX 523

1 Definite Integrals, 523
2 Fundamental Physical Constants, 524
3 Physical Constants for Constituents of Air, 524

SUBJECT INDEX 525

SYMBOL INDEX 535