

Contents

1. Microphysics of Gases	1
1.1 Thermodynamics	2
1. Equation of State of a Perfect Gas	2
2. First Law of Thermodynamics	3
3. Second Law of Thermodynamics	7
4. Thermal Properties of a Perfect Gas	9
5. Some Consequences of the Combined First and Second Laws	10
1.2 Kinetic Theory	11
6. The Distribution Function and Boltzmann's Equation	11
7. The Collision Integral	15
8. The Maxwellian Velocity Distribution	24
9. Boltzmann's <i>H</i> -Theorem	28
10. The Time of Relaxation	29
1.3 Classical Statistical Mechanics	35
11. Thermodynamic Probability and Entropy	35
12. Boltzmann Statistics	37
13. Ionization	48
14. Thermodynamic Properties of Ionizing Hydrogen	50
2. Dynamics of Ideal Fluids	55
2.1 Kinematics	55
15. Velocity and Acceleration	55
16. Particle Paths, Streamlines, and Streaklines	57
17. The Euler Expansion Formula	58
18. The Reynolds Transport Theorem	60
19. The Equation of Continuity	60
20. Vorticity and Circulation	62
21. The Cauchy–Stokes Decomposition Theorem	64
2.2 Equations of Motion and Energy	68
22. The Stress Tensor	68
23. The Momentum Equation	70
24. The Energy Equation	77

3. Dynamics of Viscous and Heat-Conducting Fluids	82
3.1 Equations of Motion and Energy: The Continuum View	82
25. The Stress Tensor for a Newtonian Fluid	82
26. The Navier–Stokes Equations	86
27. The Energy Equation	88
28. Similarity Parameters	93
3.2 Equations of Motion and Energy: The Kinetic Theory View	96
29. The Mean Free Path and Transport Phenomena	96
30. Moments of the Boltzmann Equation	102
31. Conservation Equations for Equilibrium Flow	106
32. The Chapman–Enskog Solution for Nonequilibrium Flow	107
33. Evaluation of the Transport Coefficients	117
4. Relativistic Fluid Flow	128
4.1 Basic Concepts of Special Relativity	128
34. The Relativity Principle	129
35. The Lorentz Transformation	130
36. Relativistic Kinematics of Point Particles	138
37. Relativistic Dynamics of Point Particles	140
4.2 Relativistic Dynamics of Ideal Fluids	144
38. Kinematics	144
39. The Equation of Continuity	145
40. The Material Stress-Energy Tensor	147
41. The Four-Force Density	149
42. The Dynamical Equations	150
43. The Kinetic Theory View	152
4.3 Relativistic Dynamics of Nonideal Fluids	160
44. Kinematics	160
45. The Stress-Energy Tensor	162
46. The Energy Equation	164
47. The Equations of Motion	166
5. Waves, Shocks, and Winds	169
5.1 Acoustic Waves	169
48. The Wave Equation	169
49. Propagation of Acoustic Waves	173
50. Wave Energy and Momentum	177
51. Damping of Acoustic Waves by Conduction and Viscosity	179
5.2 Acoustic-Gravity Waves	184
52. The Wave Equation and Wave Energy	184
53. Propagation of Acoustic-Gravity Waves in an Isothermal Medium	190

5.3 Shock Waves	226
55. The Development of Shocks	227
56. Steady Shocks	230
57. Shock Structure	241
58. Propagation of Weak Shocks	259
59. Numerical Methods	266
60. Propagating Strong Shocks	288
5.4 Thermally Driven Winds	295
61. Basic Model	295
62. Physical Complications	301
6. Radiation and Radiative Transfer	309
6.1 The Radiation Field	311
63. The Specific Intensity and Photon Distribution Function	311
64. The Mean Intensity and Radiation Energy Density	312
65. The Radiative Energy Flux and Momentum Density	313
66. The Radiation Pressure Tensor	314
6.2 Thermal Radiation	316
67. Planck's Law	317
68. Stefan's Law	318
69. Thermodynamics of Equilibrium Radiation	319
70. Thermodynamics of Equilibrium Radiation Plus a Perfect Gas	320
71. Thermodynamics of Equilibrium Radiation Plus an Ionizing Gas	322
6.3 The Interaction of Radiation and Matter	324
72. Absorption, Emission, and Scattering	325
73. The Einstein Relations	329
74. The Einstein–Milne Relations	331
75. Opacity and Emission Coefficients	332
6.4 The Equation of Transfer	333
76. Derivation of the Transfer Equation	333
77. Optical Depth and Source Function	336
78. Moments of the Transfer Equation	337
6.5 Solution of the Transfer Equation	341
79. Formal Solution	343
80. The Diffusion Limit	350
81. The Wave Limit	353
82. The Grey Atmosphere, Mean Opacities, and Multigroup Methods	355
83. Numerical Methods	366

6.6	Statistical Equilibrium in the Presence of a Radiation Field	386
	84. The Microscopic Implications of LTE	386
	85. Non-LTE Rate Equations	389
	86. Thermal Properties of a Nonequilibrium Gas	395
6.7	Solution of the Coupled Transfer and Statistical Equilibrium Equations in Static Media	396
	87. The Two-Level Atom	396
	88. The Complete Linearization Method	402
7.	The Equations of Radiation Hydrodynamics	409
7.1	Lorentz Transformation of the Transfer Equation	411
	89. The Photon Four-Momentum	412
	90. Transformation Laws for the Specific Intensity, Opacity, and Emissivity	413
	91. The Radiation Stress-Energy Tensor and Four-Force Vector	414
	92. Covariant Form of the Transfer Equation	418
7.2	The Dynamical Equations for a Radiating Fluid	421
	93. The Inertial-Frame Transfer Equation for a Moving Fluid	421
	94. Inertial-Frame Equations of Radiation Hydrodynamics	426
	95. The Comoving-Frame Equation of Transfer	432
	96. Comoving-Frame Equations of Radiation Hydrodynamics	448
7.3	Solution of the Equations of Radiation Hydrodynamics	455
	97. Radiation Diffusion Methods	457
	98. Transport Solution in the Comoving Frame	481
	99. Transport Solution by Mixed-Frame and VERA-Code Methods	494
8.	Radiating Flows	507
8.1	Small-Amplitude Disturbances	507
	100. Radiative Damping of Temperature Fluctuations	507
	101. Propagation of Acoustic Waves in a Radiating Fluid	521
	102. Propagation of Acoustic-Gravity Waves in a Radiating Fluid	536
8.2	Nonlinear Flows	549
	103. Thermal Waves	549
	104. Steady Shocks	557
	105. Propagating Shocks	585
	106. Ionization Fronts	611
	107. Radiation-Driven Winds	627

Appendix: Elements of Tensor Calculus	650
A1. Notation	650
A2. Cartesian Tensors	651
A3. General Tensors	664
Glossary of Physical Symbols	684
Index	697