CONTENTS

1. General properties of plasmas and elementary processes 1

1. Elementary description 2
1.1. Fundamental parameters 2
1.2. Types of interaction in plasmas 7
1.3. Macroscopic description of plasmas : distribution functions 8
1.4. Concepts concerning collisions and cross sections 13
1.7. Mutual repulsion : space charge effects 23
2. Fundamental processes 24
2.1. Elastic collisions 26
2.2. Excitation phenomena 30
2.3. Ionization phenomena 33
2.4. Capture phenomena : formation of negative ions 42
2.5. Recombination phenomena 42
2.6. Particle emission by solids and surface effects 45
3. Formation and disintegration of a plasma 47
3.1. Formation of a plasma and high-frequency discharges 47
3.2. Disintegration of a plasma 56
4. High temperature plasma and thermonuclear fusion 57
4.1. Physical processes in a hot plasma 57
4.2. Binary and multiple corpuscular processes 58
4.3. Bremsstrahlung and excitation radiation 64
4.4. Charge transfer 66
4.5. Nuclear reactions 66
4.6. Pinch effect 69
5. A survey of collective processes 70

2. Principles of statistical mechanics 73

1. State of equilibrium 73
1.1. Fundamental definitions and results 73
1.2. Liouville's theorem. Evolution in time and total equilibrium 76
1.3. Uniform, microcanonical and canonical ensembles 78
1.4. Notes on the bases of the statistical method 80
1.5. Equilibrium distribution and equation of state 84
1.6. Expansion of the equation of state in powers of density 89
1.7. Bogolyubov's method 96
2. Evolutional systems or nonequilibrium systems 101
2.1. Establishment of the BBGKY equations 101
2.2. Transition from the BBGKY equations to Boltzmann's equations 104
3. Applications of the general principles to plasma physics 118

3.1. Plasmas in equilibrium 118
3.2. Kinetic equations and evolutional phenomena 137

3. Classical dynamics of binary collisions 143

1. Introduction 143
2. Definitions 144
3. The conservation equations 147
4. Investigation of the trajectory and scattering calculation 149
5. Return to the lab. system 153
6. Definition of elastic scattering cross sections 160
7. Laws of force and calculation of cross sections 164
8. Intermolecular forces 171

4. Motion of charged particles in electric and magnetic fields Brownian motion of charge carriers 174

1. Individual motion of a charged particle 174
1.1. The general equations of motion 174
1.2. Analysis of particular cases 176
A. Case of a sole electric field 176
B. The case of a constant and uniform magnetic field 184
C. The case of nonuniform or time-dependent magnetic fields 201
2. Brownian motion of charged particles in an electromagnetic field 238
2.1. Brownian motion — a general review 238
2.2. Brownian motion of a charged particle 242
2.3. Energy relations 245
2.4. Diffusion and random walk 247

5. Boltzmann's integro-differential equation. Fundamental properties. Maxwell's transport equations 250

1. Boltzmann's integro-differential equation 250
2. Definition of the distribution functions in kinetic gas theory 250
3. The flux associated with the molecular properties 253
4. Gas mixtures 259
5. Establishment of the Boltzmann's equation 262
5.1. Boltzmann's equation in terms of cross sections 267
6. The effect of a magnetic field on Boltzmann's equation 269
7. Maxwell's transport equations 270
8. Particular expression of the collision term 272
9. The collision invariants 275

6. Macroscopic relations. Equations of dynamics and hydrodynamics of plasma 277

1. A neutral one-component fluid. The hydrodynamic equations 278
2. The neutral multi-component fluid 284
3. The ionized multi-component gas 289
4. Particular cases of general equations 297
4.1. The completely ionized gas 299
4.2. Ternary mixture 301

5. Steady-state solutions to the general plasma equations. The magnetohydrostatic equations 307
5.1. The completely ionized gas 308
5.2. Ternary mixture 311
6. Magnetohydrodynamics of plasma. Various applications 312
6.1. General equations 312
6.2. Application to magnetohydrostatics. Confinement 318
6.3. The coefficients of conductivity and diffusion in the presence of a magnetic field 320
7. Linearization of the general equations and the propagation of waves 325

7. The *H* theorem. The properties of the Maxwellian state of plasmas. The mean free path. Application to the transport phenomena (viscosity, diffusion, conductivity) 335

1. The *H* theorem 335
1.1. Introduction 335
1.2. Boltzmann's *H* theorem : equilibrium solutions 335
1.3. The properties of the Maxwellian state 339
1.4. Steady state of a gas in a container with reflecting walls 341
1.5. Steady state of a gas in the presence of an external force ($F \neq 0$) 343
1.6. The *H* theorem for a mixture of gases 347
2. Kinetic theory of mean free path 348
2.1. Calculation of the total number N_{12} of collision events 348
2.2. Definition of the collision frequency and the mean free path according to Maxwell 351
2.3. Free path and collision frequency of a particle of given velocity 353
2.4. Probability of observing a free path of given length 356
2.5. The mean free path according to Tait 357
2.6. Persistence of velocities after the collision 358
2.7. The ratio of the mean persistencies 360
3. Transport phenomena in a plasma 360
3.1. Flux of molecular properties 360
3.2. The transport coefficients 367
3.3. Corrections to the elementary theory of m. f. p. 370
3.4. The m. f. p. theory of thermal conduction and diffusion within a plasma in the presence of a magnetic field 377
3.5. The case where the force F is produced by an electric field E 380
3.6. The Leduc-Righi effect and the Nernst effect 381
3.7. Conductivity in the presence of an alternating field 382
3.8. Return to the theory of the mean motion of the electron in a magneto-active plasma 391

8. General methods of approximate solution of Boltzmann's integro-differential equation 396

1. Introduction and historical review 396
2. The fundamental ideas of the present chapter 400
2.1. Properties of the collision integrals and the Maxwell equations 401
2.2. Properties of the linearized operators $L(\Phi)$ and $K_{ij}(\Phi_i)$ 402
2.3. Grad's method 407

3. Boltzmann's equation and equation of moments of the distribution function 409
4. General iteration method (Maxwell, Ikenberry and Truesdell) 415
5. Grad's method 422
5.1. The case of Maxwell particles 424
5.2. The general case (arbitrary interaction law) 425
6. The normal solutions by Hilbert, Enskog and Chapman 437
6.2. Hilbert's method 440
6.3. Transition to Enskog's method 446
6.4. The Enskog-Chapman method 450
6.5. Calculation of $f^{(1)}$ (first-order approximation) 457
6.6. Calculation of $f^{(2)}$ (second-order approximation) 471
6.7. Comparison of the iterative method (Maxwell-Truesdell) with the method of " normal " solutions (Enskog-Chapman) 481
7. Method of linearizing Boltzmann's equation 488
7.2. Linearization about $f^{(0)}$ 488
7.3. Linearization about a locally Maxwellian function $f^{(0)}$ 505
8. Equations allied with Boltzmann's equation 506
8.1. Highly rarefied gases 506
8.2. The modified Boltzmann equation 508
9. Method of solving the linearized Boltzmann equation satisfied by a Lorentz plasma 510
9.1. General features 510
9.2. Analysis of the electron distribution f_e in a Lorentz plasma 513
9.3. Expansion of the electron distribution f_e in a tensor form (irreducible). 521
9.4. The general equations of first order 524
9.5. Solutions to the system (8-401) for a weak electric field 527
9.6. Notes on the general tensor form of Boltzmann's equation 528
9.7. Study of the steady ion distribution f_i in the case of strong electric fields 530

Appendix I. Dyad and tensor notations used in the present book 533

1. The vector gradient 533
2. Dyads and tensors 534
3. Products of vectors and tensors 536
4. Theorems concerning the dyads 537
5. Dyadic differential operators 538
6. Integral formulas 540
7. Notations in kinetic gas theory 542

Appendix II. Spherical functions 546

1. Note on the spherical function 546
2. Hermite polynomials and Laguerre-Sonine polynomials 555
3. The Sonine polynomial $T_m^{(n)}(x)$ and $S_m^{(n)}(x)$ 558
4. Tensorial Hermite polynomials 559
5. Calculation of certain useful integrals 564
6. Applications to the kinetic gas theory. Relations between spherical tensors and Hermite tensors and comparison of the various expansions of the distribution function 568

6.1. Relations between spherical tensors and Hermite tensors 568
6.2. Comparison of the various expansions of the velocity distribution function 569
7. Calculation of the first moments of distribution functions 573

Appendix III. Calculations of various integrals derived from the collision integral 578

1. Calculation of the terms in $C(V^n)$ 578
1.1. Calculation of $C(V^2)$ and $C(V^3)$ for Maxwell particles 579
2. Calculation of the integrals $C(Y\ 2r/\nu)$ for Maxwell particles 582
3. The case of an arbitrary law of force. Grad's method 593

Appendix IV. 1. The properties of the collision integrals. The collision invariants 598

2. The linear operator $I(\Phi)$ 601
3. The eigenfunctions of L_M and K_M for the $1/r^5$-law 607
4. The case of an arbitrary law of interaction. The integrals $\Omega^{(l)}(\rho)$ 617

Reference list 621

Index of notations 625

Index 629