

Table of Contents

1. Introduction	1
2. Introduction to the Physics of Nonideal Plasmas	7
2.1 The Microscopic and Statistical Description of a Fully Ionized Plasma.....	7
2.2 Equilibrium Distribution Function. Degenerate and Non-degenerate Plasmas	10
2.3 The Vlasov Equation	14
2.4 Dynamical Screening	17
2.5 Self-Energy and Stopping Power.....	23
2.6 Thermodynamic Properties of Plasmas. The Plasma Phase Transition	26
2.7 Bound States in Dense Plasmas. Lowering of the Ionization Energy	31
2.8 Ionization Equilibrium and Saha Equation. The Mott-Transition	35
2.9 The Density-Temperature Plane	40
2.10 Boltzmann Kinetic Equation	43
2.11 Transport Properties	46
2.12 Ionization Kinetics	57
3. Quantum Statistical Theory of Charged Particle Systems	65
3.1 Quantum Statistical Description of Plasmas.....	65
3.2 Method of Green's Functions.....	70
3.2.1 Correlation Functions and Green's Functions.....	70
3.2.2 Spectral Representations and Analytic Properties of Green's Functions	75
3.2.3 Analytical Properties, Dispersion Relations	80
3.3 Equations of Motion for Correlation Functions and Green's Functions	83
3.3.1 The Martin-Schwinger Hierarchy	83
3.3.2 The Hartree-Fock Approximation	86

VIII Table of Contents

3.3.3	Functional Form of the Martin–Schwinger Hierarchy	88
3.3.4	Self-Energy and Kadanoff–Baym Equations	92
3.3.5	Structure and Properties of the Self-Energy. Initial Correlation	97
3.3.6	Gradient Expansion. Local Approximation	101
3.4	Green’s Functions and Physical Properties	103
3.4.1	The Spectral Function. Quasi-Particle Picture	103
3.4.2	Description of Macroscopic Quantities	109
4.	Systems with Coulomb Interaction	117
4.1	Screened Potential and Self-Energy	117
4.2	General Response Functions	120
4.3	The Kinetics of Particles and Screening. Field Fluctuations	123
4.4	The Dielectric Function of the Plasma. General Properties, Sum Rules	130
4.5	The Random Phase Approximation (RPA)	136
4.5.1	The RPA Dielectric Function	136
4.5.2	Limiting Cases. Quantum and Classical Plasmas	141
4.5.3	The Plasmon–Pole Approximation	146
4.6	Excitation Spectrum, Plasmons	148
4.7	Fluctuations, Dynamic Structure Factor	154
4.8	Static Structure Factor and Radial Distribution Function	161
4.9	Dielectric Function Beyond RPA	163
4.10	Equations of Motion for Density–Density Correlation Functions. Schrödinger Equation for Electron–Hole Pairs	165
4.11	Self-Energy in RPA. Single-Particle Spectrum	170
5.	Bound and Scattering States in Plasmas.	
	Binary Collision Approximation	179
5.1	Two-Time Two-Particle Green’s Function	179
5.2	Bethe–Salpeter Equation in Dynamically Screened Ladder Approximation	185
5.3	Bethe–Salpeter Equation for a Statically Screened Potential	189
5.4	Effective Schrödinger Equation. Bilinear Expansion	192
5.5	The T -Matrix	196
5.6	Two-Particle Scattering in Plasmas. Cross Sections	205
5.7	Self-Energy and Kadanoff–Baym Equations in Ladder Approximation	209
5.8	Dynamically Screened Ladder Approximation	212

5.9	The Bethe–Salpeter Equation in Local Approximation.	
	Thermodynamic Equilibrium	218
5.10	Perturbative Solutions. Effective Schrödinger Equation	223
5.11	Numerical Results	227
6.	Thermodynamics of Nonideal Plasmas	237
6.1	Basic Equations	237
6.2	Screened Ladder Approximation	240
6.3	Ring Approximation for the EOS.	
	Montroll–Ward Formula	242
6.3.1	General Relations	242
6.3.2	The Low Density Limit (Non-degenerate Plasmas)	250
6.3.3	High Density Limit. Gell-Mann–Brueckner Result	254
6.3.4	Padé Formulae for Thermodynamic Functions	256
6.4	Next Order Terms	260
6.4.1	e^4 -Exchange and e^6 -Terms	260
6.4.2	Beyond Montroll–Ward Terms	262
6.5	Equation of State in Ladder Approximation. Bound States	264
6.5.1	Ladder Approximations of the EOS.	
	Cluster Coefficients	264
6.5.2	Bound States. Levinson Theorem	274
6.5.3	The Second Virial Coefficient for Systems of Charged Particles	283
6.5.4	Equation of State in Dynamically Screened Ladder Approximation	289
6.5.5	Density Expansion of Thermodynamic Functions of Non-degenerate Plasmas	295
6.5.6	Bound States and Chemical Picture. Mott Transition	298
6.6	Thermodynamic Properties of the H-Plasma	303
6.6.1	The Hydrogen Plasma	303
6.6.2	Fugacity Expansion of the EOS. From Physical to Chemical Picture	306
6.6.3	The Low-Density H-Atom Gas	310
6.6.4	Dense Fluid Hydrogen	316
6.7	The Dense Partially Ionized H-Plasma	325
7.	Nonequilibrium Nonideal Plasmas	337
7.1	Kadanoff–Baym Equations. Ultra-fast Relaxation in Dense Plasmas	337
7.2	The Time-Diagonal Kadanoff–Baym Equation	342
7.3	The Quantum Landau Equation	347
7.4	Dynamical Screening, Generalized Lenard–Balescu Equation	353

X Table of Contents

7.5	Particle Kinetics and Field Fluctuations.	
	Plasmon Kinetics	357
7.6	Kinetic Equation in Ladder Approximation.	
	Boltzmann Equation	364
7.7	Bound States in the Kinetic Theory	370
7.7.1	Bound States and Off-Shell Contributions	370
7.7.2	Kinetic Equations in Three-Particle Collision Approximation	371
7.7.3	The Weak Coupling Approximation. Lenard–Balescu Equation for Atoms	378
7.8	Hydrodynamic Equations	381
8.	Transport and Relaxation Processes in Nonideal Plasmas	385
8.1	Rate Equations and Reaction Rates	385
8.1.1	T -Matrix Expressions for the Rate Coefficients	386
8.1.2	Rate Coefficients and Cross Sections	388
8.1.3	Two-Particle States, Atomic Form Factor	392
8.1.4	Density Effects in the Cross Sections	393
8.1.5	Rate Coefficients for Hydrogen and Hydrogen-Like Plasmas	395
8.1.6	Dynamical Screening	399
8.2	Relaxation Processes	403
8.2.1	Population Kinetics in Hydrogen and Hydrogen-Like Plasmas	404
8.2.2	Two-Temperature Plasmas	407
8.2.3	Adiabatically Expanding Plasmas	414
8.3	Quantum Kinetic Theory of the Stopping Power	416
8.3.1	Expressions for the Stopping Power of Fully Ionized Plasmas	416
8.3.2	T -Matrix Approximation and Dynamical Screening	421
8.3.3	Strong Beam–Plasma Correlations. Z Dependence	423
8.3.4	Comparison with Numerical Simulations	425
8.3.5	Energy Deposition in the Target Plasma	428
8.3.6	Partially Ionized Plasmas	429
9.	Dense Plasmas in External Fields	435
9.1	Plasmas in Electromagnetic Fields	435
9.1.1	Kadanoff–Baym Equations	435
9.1.2	Kinetic Equation for Plasmas in External Electromagnetic Fields	440
9.1.3	Balance Equations. Electrical Current and Energy Exchange	445

9.1.4	Plasmas in Weak Laser Fields. Generalized Drude Formula	449
9.1.5	Absorption and Emission of Radiation in Weak Laser Fields	451
9.1.6	Plasmas in Strong Laser Fields. Higher Harmonics	454
9.1.7	Collisional Absorption Rate in Strong Fields	457
9.1.8	Results for the Collision Frequency	461
9.1.9	Effects of Strong Correlations	466
9.2	The Static Electrical Conductivity	468
9.2.1	The Relaxation Effect	469
9.2.2	Lorentz Model with Dynamic Screening, Structure Factor	475
9.2.3	Chapman-Enskog Approach to the Conductivity	479
9.2.4	Partially Ionized Hydrogen Plasma	486
9.2.5	Nonideal Alkali Plasmas	492
9.2.6	Dense Metal Plasmas	497