

Contents

1. Introduction	1
1.1 The Subject of Laser Physics at Relativistic Intensities	1
1.2 A Review of Basic Studies of Laser Physics at Relativistic Intensities	5
1.2.1 Nonlinear Propagation and Self-Focusing of Light in Matter	5
1.2.2 Charged Particle Motions in Electromagnetic Fields ..	6
1.2.3 Nonlinear Electromagnetic Waves in Plasmas	7
1.2.4 Scattering of Intense Electromagnetic Radiation in Plasmas	7
1.2.5 Interactions of Intense, Ultrashort, Laser Pulses with Underdense Plasmas	8
1.2.6 Interactions of Relativistically Intense Laser Radiation with Overdense Plasmas	11
2. Fundamentals of Cold Plasma Electrodynamics	13
2.1 Basic Cold Plasma Electrodynamics Equations in Relativistic Notation	13
2.2 Basic Equations in 3-D Form	16
2.3 Potential and Vortex Components of Momentum	19
2.4 Electron Fluid Dynamics with Inertially Frozen Ions	20
2.4.1 Canonical Variables.....	21
2.4.2 Examples of Exact Solutions	22
3. Relativistically Intense Electromagnetic Waves in Plasmas	27
3.1 The Akhiezer–Polovin Problem	27
3.2 Linearly Polarized Plane Electromagnetic Waves	29
3.2.1 Self-Modulation at Relativistic Intensities	29
3.2.2 Asymptotic Theory in the High-Frequency Limit	31
3.2.3 Quasi-Relativistic Limit	35
3.3 Circularly Polarized Plane Electromagnetic Waves	37

4. Instabilities of Circularly Polarized	
Plane Electromagnetic Waves in Plasmas	39
4.1 Equations of Circularly Polarized Wave Instability in Plasmas	40
4.2 Slab Geometry Instability Equations	42
4.2.1 Conserved Circular Polarization Approximation	42
4.2.2 Instability Growth Rates in Slab Geometry	43
4.3 3-D Instability Growth Rates	47
4.4 Conclusions	53
5. Instabilities of Linearly Polarized	
Plane Electromagnetic Waves in Plasmas	55
5.1 3-D Instability Equations	55
5.2 Scattering of Linearly Polarized Electromagnetic Waves in 1-D Geometry	58
5.2.1 One-Dimensional Scattering Equations	58
5.2.2 Propagation of Perturbations Parallel to the Pump Wave	59
5.3 Scattering Diagrams for 3-D Instability	63
5.4 Conclusions	68
6. Models of Nonlinear Propagation of Relativistically Intense Ultrashort	
Laser Pulses in Plasmas	73
6.1 The Physical Model	74
6.2 Derivation of the Basic Model Equations	75
6.3 Envelope Approximation	78
6.4 Long Beam and Large Aperture Limits	79
6.4.1 Long Beam Limit	80
6.4.2 Large Laser Pulse Aperture Limit	81
6.5 Filamentation and Self-Modulation of Relativistically Intense Laser Radiation in Cold Underdense Plasmas	82
6.6 Laser Radiation Stimulated Scattering by Plasmons and Third-Harmonics Generation	86
6.7 Conclusions	89
7. Intense Laser Pulse Solitons in Plasmas	91
7.1 Soliton Equations and Numerical Solutions	91
7.2 One-Dimensional Laser Pulse Solitons in the WKB Approximation	93
7.3 Conclusions	96
8. Relativistic and Charge-Displacement Self-Channeling of Intense Ultrashort Laser Pulses in Plasmas	97
8.1 Stationary Self-Localized Modes of Beam Propagation	97

8.1.1	Slab Geometry Solitons	98
8.1.2	Axially Symmetrical Eigenmodes: Relativistic and Charge-Displacement Self-Channeling Critical Power	98
8.2	General Sufficient Condition for Relativistic and Charge-Displacement Self-Channeling	103
8.3	Propagation of Axially Symmetrical Laser Beams in Cold Underdense Plasmas	104
8.3.1	Problem Formulation in Terms of Propagation Distance	104
8.3.2	Relativistic and Charge-Displacement Self-Channeling	106
8.4	Filamentation Stability of Relativistic and Charge-Displacement Self-Channeling	112
8.4.1	Eigenmode Stability to Filamentation	114
8.4.2	Stability of Initially Hyper-Gaussian and Gaussian Beams in Initially Homogeneous Plasmas	115
8.4.3	Filamentation Stability in Preformed Plasma Columns	122
8.5	Observation of Relativistic and Charge-Displacement Self-Channeling of Intense Subpicosecond Ultraviolet (248 nm) Radiation in Plasmas	125
8.6	Conclusions	132
9.	Dynamics of Relativistic and Charge-Displacement Self-Channeling in Time and 2D Space	135
9.1	Superintense Two-Dimensional Solitons, Self-Modulation, and Spectral Broadening	135
9.1.1	Laser Beam Stabilization and the Formation of a Two-Dimensional Solitary Wave	135
9.1.2	Giant Broadening of Laser Pulse Spectra	137
9.2	Nonlinear Wave Equation Model	139
9.2.1	A Comparison of Simulations Based on the Modified Nonlinear Schroedinger Equation and on the Nonlinear Wave Equation	141
9.2.2	Laser Pulse Self-Modulation in a Self-Channeling Regime	145
9.3	Conclusions	147
10.	Propagation of Laser Radiation in Multiple-Stage Ionized Matter	149
10.1	General Description of Ionizational Defocusing	150

XII Contents

10.2 Simulations of Ionizational Defocusing of Laser Pulses in Gases	153
10.3 Experimental Demonstration of Ionization-Induced Defocusing of Short-Pulse, High-Power Lasers in Gases	158
10.4 Spectral Blueshifting of Short-Pulse, High-Power Lasers in Gases	160
10.5 Thomas–Fermi Atom in an Intense Field	161
11. Experiments on Laser–Matter Interaction in the Relativistic Regime	
11.1 Enhancement of Self-Channeling Distance by an Exterior Supply of Energy	166
11.2 X-Ray Laser	170
11.3 Harmonic Excitation	178
11.3.1 High-Order Harmonic Generation in Gases	178
11.3.2 Harmonic Generation in Plasmas	180
11.4 Generation of Intense Electrostatic Fields and Acceleration of Electrons	182
11.5 Generation of Superintense Magnetic Fields	188
11.6 Interaction of Free Electrons with Ultrashort Laser Pulses	190
11.7 Fast Igniter Scheme	192
11.8 Pulse Generator of Neutrons	199
References	201
Index	217