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

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** 165
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

http://www.springer.com/978-3-540-43446-7

Laser Physics at Relativistic Intensities

Borovsky, A.V.; Galkin, A.L.; Shiryaev, O.B.; Auguste, T.

2003, XII, 220 p., Hardcover
ISBN: 978-3-540-43446-7