



# Contents

<b>1. Introduction . . . . .</b>	<b>1</b>
1.1. Data on the Structure of the Ionosphere. . . . .	1
1.2. Features of Nonlinear Phenomena in the Ionosphere . . . . .	4
1.2.1. Nonlinearity Mechanisms . . . . .	4
1.2.2. Qualitative Character of Nonlinear Phenomena . . . . .	7
1.2.3. Brief Historical Review. . . . .	11
<b>2. Plasma Kinetics in an Alternating Electric Field . . . . .</b>	<b>14</b>
2.1. Homogeneous Alternating Field in a Plasma (Elementary Theory). . . . .	14
2.1.1. Electron Current—Electronic Conductivity and Dielectric Constant. . . . .	15
2.1.2. Electron Temperature . . . . .	19
2.1.3. Ion Current—Heating of Electrons and Ions . . . . .	29
2.2. The Kinetic Equation . . . . .	34
2.2.1. Simplification of the Kinetic Equation for Electrons. . . . .	35
2.2.2. Transformation of the Electron Collision Integral. .	40
2.2.3. Inelastic Collisions . . . . .	50
2.3. Electron Distribution Function. . . . .	58
2.3.1. Strongly Ionized Plasma . . . . .	59
2.3.2. Weakly Ionized Plasma . . . . .	69
2.3.3. Arbitrary Degree of Ionization—Concerning the Elementary Theory . . . . .	82
2.4. Ion Distribution Function . . . . .	87
2.4.1. Simplification of the Kinetic Equation . . . . .	87
2.4.2. Distribution Function . . . . .	88
2.4.3. Ion Temperature, Ion Current. . . . .	91

2.5. Action of Radio Waves on the Ionosphere . . . . .	94
2.5.1. Ionization Balance in the Ionosphere . . . . .	94
2.5.2. Effective Frequency of Electron and Ion Collisions—Fraction of Lost Energy . . . . .	99
2.5.3. Electron and Ion Temperatures in the Ionosphere . . . . .	106
2.5.4. Heating of the Ionosphere in an Alternating Electric Field . . . . .	108
2.5.5. Perturbations of the Electron and Ion Concentrations . . . . .	111
2.5.6. Artificial Ionization of the Ionosphere— Heating of Neutral Gas . . . . .	113
<b>3. Self-Action of Plane Radio Waves . . . . .</b>	<b>125</b>
3.1. Simplification of Initial Equations . . . . .	125
3.1.1. Nonlinear Wave Equation . . . . .	125
3.1.2. Nonlinear Geometrical Optics of a Plane Wave . .	127
3.2. Effect of Nonlinearity on the Amplitude and Phase of the Wave . . . . .	129
3.2.1. Self-Action of a Weak Wave . . . . .	129
3.2.2. Self-Action of a Strong Wave . . . . .	132
3.2.3. Self-Action of Waves in the Case of Artificial Ionization . . . . .	144
3.3. Change of Wave Modulation . . . . .	147
3.3.1. Weak Wave . . . . .	147
3.3.2. Change of Amplitude Modulation of Strong Wave . . . . .	150
3.3.3. Phase Modulation . . . . .	157
3.3.4. Nonlinear Distortion of Pulse Waveform . . . .	158
3.4. Generation of Harmonic Waves and Nonlinear Detection . . . . .	161
3.4.1. Frequency Tripling . . . . .	161
3.4.2. Nonlinear Detection . . . . .	164
3.5. Self-Action of Radio Waves in the Lower Ionosphere . .	165

<b>4. Interaction of Plane Radio Waves . . . . .</b>	<b>176</b>
4.1. Cross Modulation . . . . .	176
4.1.1. Weak Waves . . . . .	176
4.1.2. Strong Perturbing Wave . . . . .	183
4.1.3. Resonance Effects near the Electron Gyrofrequency . . . . .	188
4.2. Interaction of Unmodulated Waves . . . . .	191
4.2.1. Interaction of Short Pulses . . . . .	191
4.2.2. Change in the Absorption of a Wave Propagating in a Perturbed Plasma Region . . . . .	194
4.2.3. Generation of Waves with Combination Frequencies . . . . .	196
4.3. Radio Wave Interaction in the Lower Ionosphere . . . . .	198
4.3.1. Cross Modulation . . . . .	198
4.3.2. Fejer's Method . . . . .	201
4.3.3. Nonstationary Processes in the Interaction of Strong Radio Waves . . . . .	204
<b>5. Self-Action and Interaction of Radio Waves in an Inhomogeneous Plasma . . . . .</b>	<b>207</b>
5.1. Inhomogeneous Electric Field in a Plasma . . . . .	207
5.1.1. Fundamental Equations . . . . .	207
5.1.2. Distribution of Density and Temperatures in Plasma . . . . .	216
5.2. Kinetics of Inhomogeneous Plasma . . . . .	221
5.2.1. Kinetic Coefficients. Elementary Theory . . . . .	221
5.2.2. Kinetic Theory . . . . .	225
5.2.3. Fully Ionized Plasma . . . . .	234
5.3. Modification of the F Region of the Ionosphere by Radio Waves . . . . .	235
5.3.1. Modification of the Electron Temperature and of the Plasma Concentration . . . . .	235
5.3.2. Radio Wave Reflection Region . . . . .	245
5.3.3. Growth and Relaxation of the Perturbations . . . . .	253

5.4. Focusing and Defocusing of Radio Wave Beams . . . . .	258
5.4.1. Nonlinear Geometrical Optics . . . . .	259
5.4.2. Defocusing of Narrow Beams . . . . .	264
5.4.3. Mutual Defocusing . . . . .	275
5.4.4. Thermal Focusing in the Lower Ionosphere . . . . .	278
<b>6. Excitation of Ionosphere Instability . . . . .</b>	<b>282</b>
6.1. Self-Focusing Instability . . . . .	283
6.1.1. Spatial Instability of a Homogeneous Plasma . . . . .	283
6.1.2. Instability in the Wave-Reflection Region . . . . .	291
6.2. Resonant Absorption and Resonance Instability . . . . .	298
6.2.1. Langmuir Oscillations in an Inhomogeneous Plasma . . . . .	299
6.2.2. Excitation of Plasma Waves . . . . .	305
6.2.3. Resonance Instability . . . . .	311
6.2.4. Absorption of Ordinary Radio Waves . . . . .	315
6.3. Parametric Instability . . . . .	321
6.3.1. Langmuir Oscillations of a Plasma in an Alternating Field . . . . .	322
6.3.2. Parametric Excitation of Langmuir Oscillations . . . . .	329
6.3.3. Parametric Instability in the Ionosphere . . . . .	335
6.3.4. Dissipative Parametric Instability . . . . .	340
<b>References . . . . .</b>	<b>353</b>
<b>Principal Symbols . . . . .</b>	<b>363</b>
<b>Subject Index . . . . .</b>	<b>367</b>

