

Contents

Preface	vii
List of Symbols	xxi

CHAPTER I

FUNDAMENTALS OF THE THEORY ON PROPAGATION OF ELECTROMAGNETIC WAVES IN PLASMA	1
--	---

Section 1.—General Introduction. Parameters of Plasma in Various Cases	1
Various Cases of Wave Propagation in Plasma (1). Plasma Parameters (2). Characteristics of Plasma (5).	

Section 2.—Basic Equations. The Nature of Approximations Employed	6
Field Equations (6). One-Dimensional Problems. Plane Waves (10). Plasma Oscillations (13). Spatial Dispersion (15). Propagation of Waves of Various Types (16).	

CHAPTER II

PROPAGATION OF WAVES IN HOMOGENEOUS AND ISOTROPIC PLASMA	21
--	----

Section 3.—Complex Dielectric Permittivity of Plasma (Elementary Theory)	21
Elementary Derivation of Expression for ϵ and σ (21). The Effective Field (27).	

Region of Applicability of the Equations Derived (32). Magnetic Permeability of Plasma (36).	
Section 4.—Kinetic Equation Method	36
The Distribution Function and the Kinetic Equation (36). Plasma in a Strong Electric Field (38). The Distribution Function and its Equation in a Weak Field (41). Transport Cross-Sections. Debye Shielding (47). Limits of Applicability of Kinetic Theory Equations (56).	
Section 5.—Some Remarks on Microprocesses in Plasma	58
Microprocesses in Plasma and Equations for Conservation of the Number of Particles of Various Types (58). Slow-Down Time for Nonequilibrium Electrons in Plasma (65). Deviation of the Distribution Function from its Equilibrium Value. Estimates for the Ionosphere (71).	
Section 6.—Dielectric Permittivity and Plasma Conductivity (Kinetic Theory)	75
General Equations (75). Collisions with Molecules (78). Collisions with Ions (79). The Role of Electron-Electron Collisions (82). The Number of Collisions in the Ionosphere (85). The Low-Frequency Case (89). The General Case (Any Frequency) (93). Collisions of Ions with Ions and Molecules (97). Dispersion Relationships (100).	
Section 7.—Propagation of Electromagnetic (Transverse) Waves in Homogeneous Plasma .	100
Refraction and Absorption Indices (100). Nonabsorptive Damping of Waves (105).	

Expressions for n and κ for Limiting Cases (106). The Real and Complex Values of Frequency (107).	
Section 8.—Allowance for Spatial Dispersion. Plasma and Acoustic Waves	109
Plasma (Longitudinal) Waves. Phenomenological Description of Spatial Dispersion (109). Kinetic Theory (116). Cherenkov Radiation in Plasma. Absorption of Plasma Waves (122). The Effect of Ions. Acoustic Waves (132). Quasi-Hydrodynamic Method (136). Longitudinal Waves in Two-Temperature Plasma (138).	
Section 9.—Summary of Basic Equations	142
Transverse Waves (144). Longitudinal Waves in Plasma (149).	
CHAPTER III	
PROPAGATION OF WAVES IN HOMOGENEOUS MAGNETOACTIVE PLASMA	153
Section 10.—The Complex Dielectric Permittivity Tensor	153
The Effect of Constant Fields on the Properties of Plasma (153). Complex Dielectric Permittivity Tensor (Elementary Theory) (156). Properties of the Tensor ϵ'_{ik} (158). Tensor ϵ'_{ik} in Other Coordinate Systems (160). Kinetic Theory (164). The Effect of Ionic Motion (168).	
Section 11.—Propagation of High-Frequency Waves in Magnetoactive Plasma	174
Expression for Indices of Refraction and Absorption $n_{1,2}$ and $\kappa_{1,2}$ (174). Certain Special Cases (178). Propagation of Waves at an	

Arbitrary Angle α to the Magnetic Field (183). Polarization of Waves (187). Normal Waves. The Case of Small Angles α (190). Consideration of Absorption (195). Quasi-Longitudinal and Quasi-Transverse Propagation (199). Critical Number of Collisions. Graphs of $n_{1,2}(\omega)$ and $x_{1,2}(\omega)$ (201). The Effect of Ions (205). The Absorption and Radiation of Electromagnetic Waves by Magnetoactive Plasma (208).	
Section 12.—Spatial Dispersion and Plasma Waves in the Presence of a Magnetic Field (Effect of Thermal Motion)	211
The Limiting Transition to Isotropic Plasma (211). Spatial Dispersion in an Anisotropic Medium (214). The Quasi-Hydrodynamic Approximations (216). Plasma Waves in Magnetoactive Plasma (220). Kinetic Theory (223). The Nature of Absorption Not Associated with Collisions (224). Results of Kinetic Theory for Longitudinal Propagation (232). Resonant Absorption at Arbitrary Angle α (239). The Region of Cherenkov Absorption (Vicinity of Resonance Frequency ω_{∞}) (248). The Case of the Ordinary Wave at Low Frequencies (264). Summary (265).	
Section 13.—Some Remarks on the Dynamics of Plasma	266
The Magnetohydrodynamic Approximation (266). Quasi-Hydrodynamic Approximations (269). On the Motion of Pure Electron — Ion Plasma and Weakly Ionized Gas (274). Stationary Motion of Weakly Ionized Gas in a Magnetic Field. The Case of the Earth's Ionosphere (278).	

Section 14.—Propagation of Low-Frequency and Magnetohydrodynamic Waves	281
Introduction (281). Magnetohydrodynamic Waves (292). Low-Frequency Waves (Quasi-Hydrodynamic Analysis (291). On the Region of Applicability of Magnetohydrodynamic Equations (295). Angles α close to $\pi/2$ (297). On the Region of Ionic Cyclotron Resonance (298). The Effect of Molecules (299). The Effect of Thermal Motion. Some Results of Kinetic Theory (Change in Velocity, Damping in the Absence of Collisions) (302).	
Section 15.—Summary of Basic Equations	310

CHAPTER IV

PROPAGATION OF WAVES IN AN INHOMOGENEOUS ISOTROPIC MEDIUM	319
Section 16.—Introduction. The Approximation of Geometric Optics	319
Wave Equations. Plane-Layered Medium (319). Exact Solutions for a Plane-Layered Medium (321). Approximate Solutions (322). The Approximation of Geometric Optics (323). A More Rigorous Treatment of the Same Problem (328). Cases When the Approximation of Geometric Optics is not Inapplicable. Total Internal Reflection (332). Reflection of Radio Waves from the Ionosphere (336). A Totally Nonreflecting Layer (337). Weak Reflection from a Layer (338). Reflection from the Discontinuity in the Derivative $\frac{dn}{dz}$ (340).	

Section 17.—Exact Solutions of the Wave Equation (Linear and Parabolic Layers; Layer $\epsilon' = \frac{a}{(b+z)^2}$)	344
Introduction (344). A Linear Layer without Absorption (345). An Absorbing Linear Layer (348). A Parabolic Layer without Absorption (353). The Layer $\epsilon' = \frac{a}{(b+z)^2}$ (356).	
Section 18.—Reflection and Transmission of Waves in the Case of “Symmetric” and “Transitional” Layers of Arbitrary Thickness	359
A Smooth Layer with Four Parameters (359). “Symmetric” Layer (360). “Transitional” Layer. Limiting Transition to a Sharp Interface (362).	
Section 19.—Oblique Incidence of Waves on a Layer	364
General Relationships. A Wave with the Electric Vector, Normal to the Plane of Incidence (364). The Approximation of Geometric Optics (368). The Ray Treatment (369). Waves with the Electric Vector in the Plane of Incidence (371). Equation for the Magnetic Field of the Wave (375).	
Section 20.—A Special Characteristic of an Electromagnetic Wave Field Propagating in an Inhomogeneous Isotropic Plasma. The Interaction of Electromagnetic and Plasma Waves.	377
Physical Description of the Phenomenon (377). Solution of the Wave Equation (379). Formation of Plasma Waves. Interaction among Various Normal Waves (394). Mutual Transformation and Interaction between Longitudinal and Transverse Waves in Plasma (402).	

Section 21.—Propagation of Pulses (Signals)	403
Fourier Representation of the Pulse Field (403). Propagation of Quasi-Monochromatic Pulse without Consideration of Spreading (406). Phase and Group Velocities of Waves (408). Spreading of Signals (411). Limits of Applicability of the Present Approximation and More Exact Results (419).	
Section 22.—Energy Density in a Dispersive Medium. Velocity of Signals in Plasma with Absorption Present	423
Introduction (423). Energy Density in a Nonabsorptive Dispersive Medium (425). The Case of an Absorptive Medium (429). Energy Density in Plasma (430). Energy Density in the Case of Combination Oscillators (432). Energy Density in Plasmatic Waves (434). Velocity of Signals in Absorptive Medium. Application to Plasma (436).	
CHAPTER V	
PROPAGATION OF WAVES IN INHOMOGENEOUS MAGNETOACTIVE PLASMA	439
Section 23.—Introduction. The Approximation of Geometric Optics	439
Wave Equations (439). The Approximation of Geometric Optics (441). Limits of Applicability of the Approximations (445). Boundary Region of the Layer and the Interaction of Normal Waves in this Case (449).	
Section 24.—Propagation of Pulses	454
Group Velocity Vector in a Magnetoactive Medium (454). The Group Velocity Vector, the Direction of the Ray, and the	

Energy Flux Vector (461). Propagation of Signals in an Inhomogeneous Medium (464).	
Section 25.—Reflection of Waves from an Inhomogeneous Layer	467
Reflection of Waves from a Layer. Angles $\alpha=0$ and $\alpha=\frac{\pi}{2}$ (467). Approximate Solution with Arbitrary Angle α (470).	
Section 26.—Limiting Polarization of Waves Emerging from a Layer of Inhomogeneous Magnetoactive Plasma	479
Introduction. Some Estimates (479). Approximate Solution (483). Results of Calculations (490).	
Section 27.—Behavior of the Wave Field, Reflection and Transmission Coefficients when Singularities are Present in the Refractive Index	497
Introduction. Singularities (Poles) in the Refractive Index (493). Rigorous Solution for the Layer $\epsilon'_{\phi\phi} = \frac{g}{(z+is)^2}$ (497). Rigorous Solution for the Layer $\epsilon'_{\phi\phi} = \frac{g^2}{z+is}$. Physical Interpretation (498). Layer $\epsilon'_{\phi\phi} = g_1^2 + \frac{g_2^2}{z+is}$ (501). The Pole of Function $(n-ix)_{1,2}^2$ in the Case of a Magnetoactive Plasma (504). Resonance Mechanism. The Effect of "Swelling" of the Field Magnetoactive Plasma (510). Case of the Earth's Ionosphere (513). Consideration of Spatial Dispersion (514).	
Section 28.—The Effect of "Tripling" the Reflected Signals (Interaction of Normal Waves at Low Values of the Angle α)	515

Region of Small Angles α Between the Magnetic Field and the Wave Normal. Description of the Phenomenon (515). Solution of the Problem by the Method of Perturbation (Region of Very Small Angles α) (519). Variational Method (Another Limiting Case) (529). Method of Phase Integrals (54). General Results for $u = \frac{\omega^2 H}{\omega^2} < 1$ (543). Equations for ϵ_0 . Consideration of Collisions (547). Results for $u = \frac{\omega^2 H}{\omega^2} > 1$ (554).	
Section 29.—Oblique Incidence of Waves on a Layer. Reciprocity Theorem	559
Introduction (559). Approximation of Geometric Optics (561). The Field in the First Approximation of Geometric Optics (564). Graphs of Functions $q_{1,2}(v)$ (567). Trajectories of Wave Normals and Rays (572). Some Special Cases (577). Leakage of Waves and the Effect of "Tripling" of Signals at Oblique Incidence (584). Wave Leakage at $u = \frac{\omega^2 H}{\omega^2} > 1$ (587). Proof of the Reciprocity Theorem (590). Generalization for the Case of a Magnetoactive Medium (592). Media with the Asymmetric Tensor ϵ'_{ik} and with Spatial Dispersion (594).	
CHAPTER VI	
REFLECTION OF RADIO WAVES FROM IONOSPHERIC LAYERS	597
Section 30.—Introduction. Reflection from an Arbitrary Smooth Layer	597
Propagation of Radio Waves in the Ionosphere (597). Parameters of the Ionosphere	

(599). Reflection of Waves from an Arbitrary Layer (602). Effective Altitude of Reflection z_e . Altitude and Frequency Characteristics (609). Parabolic Layer (613). Changes in the Layer with Time (618).	
Section 31.—Absorption	621
Effect of Absorption on the Reflection of Waves (621). Coefficient of Reflection in the Case of Low Absorption. Determination of ν_{ϕ} from Absorption Measurements (625).	
Section 32.—Structure of the Field Near the Point of Reflection	629
Structure of the Field (629). The Approximation of Geometric Optics (633). Absorption (635).	
Section 33.—Reflection and Leakage of Waves with Frequencies Close to the Critical	636
Parabolic Layer (636). Arbitrary Layer (638). Effective Altitude for a Parabolic Layer (Rigorous Solution) (646). Establishment Time for the Amplitude of a Signal (649).	
Section 34.—Reflection at Oblique Incidence	651
Reflection Point. Critical Frequency (651). Ray Treatment (653). Theorems Relating Group Paths Oblique and Normal Incidence (659). Reflection from a Spherical Layer (662). Field Intensity of Signals Reflected from the Ionosphere (664).	
Section 35.—Reflection of Waves, Making Allowance for the Effect of the Magnetic Field	671
Effect of Magnetic Field. Critical Frequency (671). Wave Phase and Coefficient	

of Reflection. Behavior of Rays (673). Quasi-Longitudinal and Quasi-Transverse Propagation (680). Oblique Incidence (683). Consideration of the Inhomogeneity of the Earth's Magnetic Field (685).

CHAPTER VII

PROPAGATION OF RADIO WAVES UNDER COSMIC CONDITIONS 687

Section 36.—Propagation of Radio Waves in the Atmosphere of the Sun 687

 Introduction (687). The Solar Corona (688). Propagation of Radio Waves in the Corona (691). Emission of Radio Waves. Effect of Refraction (699). Effects of the Magnetic Field (706). Transformation of Plasma Waves into Radio Waves (709). Absorption Not Associated with Collisions (712). The Kirchhoff Theorem in Magnetoactive Plasma (714).

Section 37.—Propagation of Radio Waves in Interstellar Medium 718

 Absorption of Radio Waves in Interstellar Gas (General Remarks) (718). Calculation of Coefficients of the Absorption in a Highly Rarefied Plasma (721). Rotation of the Plane of Polarization of Radio Waves in an Interstellar Medium (728).

CHAPTER VIII

NONLINEAR PHENOMENA IN PLASMA IN A VARIABLE ELECTROMAGNETIC FIELD 733

Section 38.—Introduction. Plasma in a Strongly Homogeneous Electric Field 733

The Condition of Small Field in Plasma. Examples (733). Formulation of the Prob- lems in the Case of a Strong Field (736). Elementary Theory (737). Accuracy of Re- sults of the Elementary Theory (747). Kinetic Theory (749). Highly Ionized Plasma (755). Weakly Ionized Plasma (757).	
Section 39.—Nonlinear Effects in Propagation of Radio Waves in Plasma (Ionosphere)	761
Introduction (761). Basic Equations (762). Self-Field Effect (765). Nonlinear Inter- action of Waves. Cross-Modulation (773). Nonlinear Interaction of Unmodulated Waves. Combination Frequencies (779). Nonlinearity Associated with Variation in Electron Concentration (783).	
Bibliography	787