

CONTENTS

PREFACE TO THE SECOND RUSSIAN EDITION	xiii
PREFACE TO THE FIRST RUSSIAN EDITION	xv
NOTATION	xvii
I. THE FUNDAMENTAL THEORY OF ELECTROMAGNETIC WAVE PROPAGATION IN PLASMAS	1
§ 1. General introduction. The plasma parameters in various cases	1
Various cases of wave propagation in plasmas	1
Plasma parameters	2
Plasma properties	3
§ 2. Fundamental equations. The nature of the approximations used	4
The field equations. The constitutive equations in linear electrodynamics	4
Frequency dispersion and spatial dispersion, and their significance in plasmas	7
The field equations neglecting spatial dispersion (a "cold" plasma)	10
One-dimensional problems. Plane waves	13
Plasma oscillations	15
Propagation of various types of waves	16
II. WAVE PROPAGATION IN A HOMOGENEOUS ISOTROPIC PLASMA	19
§ 3. The complex permittivity of a "cold" plasma: elementary theory	19
Elementary derivation of the expressions for ϵ and σ	19
The effective field	22
The range of applicability of the formulae	25
The permeability of the plasma. Allowance for spatial dispersion	27
§ 4. The method of the Boltzmann equation	28
The distribution function and the Boltzmann equation	28
A plasma in a strong electric field	29
The form of the distribution function and the equation for it in a weak field	31
Transport cross-sections. Debye screening	34
The limits of applicability of the kinetic-theory formulae	39
§ 5. Microprocesses in plasmas	40
Microprocesses in plasmas. The equations of conservation of particles of each species	40
The slowing-down time of non-equilibrium electrons in a plasma	44
The deviation of the distribution function from the equilibrium form. Estimates for the ionosphere	48

§ 6. The permittivity and conductivity of a plasma: kinetic theory	50
General relations	50
Collisions with molecules	52
Collisions with ions	53
The part played by collisions between electrons	54
The collision frequency in the ionosphere	56
Low frequencies	58
The general case of an arbitrary frequency	61
Collisions of ions with ions and molecules	63
Dispersion relations	65
§ 7. The propagation of electromagnetic (transverse) waves in a homogeneous plasma	65
The indices of refraction and absorption	65
Damping of waves in the absence of absorption	67
Expressions for n and κ in limiting cases	68
Real and complex frequencies	69
§ 8. The allowance for spatial dispersion. Plasma waves and acoustic waves	69
Plasma (longitudinal) waves. Phenomenological allowance for spatial dispersion	69
The kinetic theory	74
Cherenkov radiation in a plasma. Absorption of plasma waves	79
Absorption and the quasilinear theory of plasma waves	84
The effect of ions. Acoustic waves	91
The quasihydrodynamic method	93
Longitudinal waves in a two-temperature plasma	94
§ 9. Summary of principal formulae	97
Transverse waves	98
Longitudinal waves in a plasma	101
III. WAVE PROPAGATION IN A HOMOGENEOUS MAGNETOACTIVE PLASMA	104
§ 10. The complex permittivity tensor	104
The effect of a constant magnetic field on the properties of a plasma	104
The complex permittivity tensor: elementary theory	105
Properties of the tensor ϵ'_{ij}	107
The tensor ϵ'_{ij} in other coordinate systems	109
Kinetic theory	112
The effect of the motion of ions	115
§ 11. High-frequency wave propagation in a magnetoactive plasma	118
Expressions for the indices of refraction and absorption $n_{1,2}$ and $\kappa_{1,2}$	118
Some particular cases	121
Propagation of waves at an arbitrary angle α to the magnetic field	125
Propagation of whistlers and of "helical waves" in metals	128
Wave polarisation	129
Normal waves. The case of small angles α	131
The allowance for absorption	134
Quasilongitudinal and quasitransverse propagation	137
Propagation of two coherent normal waves. Rotation of the plane of polarisation (the Faraday effect)	138
The critical collision frequency and essential multiple roots of the dispersion relation	140

Graphs of $n_{1,2}(v)$ and $\kappa_{1,2}(v)$	142
The effect of ions on the propagation of high-frequency waves	145
Absorption and emission of electromagnetic waves by a magnetoactive plasma	147
§ 12. Spatial dispersion and plasma waves in a magnetic field: the allowance for thermal motion	150
The passage to the limit of an isotropic plasma	150
The allowance for spatial dispersion in an anisotropic medium	151
The quasihydrodynamic approximation	153
Plasma waves in a magnetoactive plasma	156
The kinetic theory	157
The nature of the collisionless absorption	157
Calculation of the absorption coefficient by means of Kirchhoff's law and the method of Einstein coefficients	162
Results of the kinetic theory for longitudinal propagation ($\alpha = 0$)	166
Resonance absorption for an arbitrary angle α	171
The Cherenkov absorption range (near the resonance frequency ω_∞)	178
The ordinary wave at low frequencies	186
Summary	187
§ 13. Some remarks on plasma dynamics	187
The hydromagnetic approximation	187
The quasihydrodynamic approximation	190
The motion of a pure electron-ion plasma and a weakly ionised gas	193
Steady motion of a weakly ionised gas in a magnetic field. The Earth's ionosphere	196
§ 14. Propagation of low-frequency and hydromagnetic waves	199
Introduction	199
Hydromagnetic waves	199
Low-frequency waves: the quasihydrodynamic approximation. Longitudinal propagation	206
The range of validity of the hydromagnetic formulae	209
Angles α close to $\frac{1}{2}\pi$. "Hybrid" resonances	210
The region of ion gyroresonance	211
The effect of molecules	213
The thermal motion. Some results of the kinetic theory: velocity change, damping in the absence of collisions	214
§ 15. Summary of principal formulae	219
IV. WAVE PROPAGATION IN AN INHOMOGENEOUS ISOTROPIC PLASMA	224
§ 16. Introduction. The approximation of geometrical optics	224
The wave equations. A medium of plane layers	224
Exact solutions for a plane-parallel medium	225
Approximate solutions	225
The approximation of geometrical optics	226
A more rigorous treatment of the same problem	229
Cases where the approximation of geometrical optics is inapplicable.	
Total internal reflection	231
The reflection of radio waves from the ionosphere	234
A completely non-reflecting layer	234
Weak reflection. The interpolation formula for $ R $ in a general layer	235
Reflection from a discontinuity of the derivative dn/dz	238

§ 17. Exact solutions of the wave equation with ε' linear, parabolic, or equal to $a/(b+z)^2$	240
Introduction	240
A linear layer without absorption	240
A linear layer with absorption	243
A parabolic layer without absorption	245
A layer with $\varepsilon' = a/(b+z)^2$	247
§ 18. Reflection and transmission of waves by “symmetrical” and “transition” layers of arbitrary thickness	249
A smooth layer with four parameters	249
A “symmetrical” layer	250
A “transition” layer. The limiting transition to a sharp boundary	251
§ 19. Oblique incidence of waves on a layer	252
General relations. A wave with the electric vector perpendicular to the plane of incidence	252
The approximation of geometrical optics	255
The ray treatment	256
Waves with the electric vector in the plane of incidence	257
The equation for the magnetic field of the wave	259
§ 20. A property of the field of an electromagnetic wave propagated in an inhomogeneous isotropic plasma. Interaction of the electromagnetic and plasma waves	260
A physical description of the phenomenon	260
The solution of the wave equation	262
The allowance for spatial dispersion and various non-linear effects	268
Allowance for the generation of plasma waves. The interaction between different normal waves	271
The mutual transformation of and interaction between longitudinal and transverse waves in a plasma	277
§ 21. The propagation of pulse signals	280
The Fourier representation of a pulse field	280
Propagation of a quasimonochromatic pulse without allowance for spreading	282
Phase and group velocities of waves	283
Spreading of pulses	284
The limits of applicability of the approximation used, and some more accurate results	290
§ 22. Energy density in a dispersive medium. The velocity of signals in plasmas when absorption is present	292
Introduction	292
Energy density in a non-absorbing dispersive medium	293
The case of an absorbing medium	296
Energy density for a model of an absorbing plasma	299
Energy density for an assembly of oscillators	300
Energy density in plasma waves	300
Velocity of signals in an absorbing medium. Application to a plasma	301
V. WAVE PROPAGATION IN AN INHOMOGENEOUS MAGNETO-ACTIVE PLASMA	304
§ 23. Introduction. The approximation of geometrical optics	304
The wave equations	304
The approximation of geometrical optics	305

The limits of applicability of the approximation of geometrical optics	308
The region near the boundary of the layer and the interaction of normal waves there	310
§ 24. Propagation of pulses	313
The group-velocity vector in an anisotropic medium	313
The case of a magnetoactive plasma	317
The group-velocity vector, the direction of the ray and the energy-flux vector	320
Propagation of pulses in an inhomogeneous medium	324
Propagation of pulses in an absorbing medium	326
§ 25. Reflection of waves from an inhomogeneous layer	329
Reflection from a layer. Angles $\alpha = 0$ and $\alpha = \frac{1}{2}\pi$	329
The approximate solution for an arbitrary angle α	330
§ 26. The limiting polarisation of waves leaving a layer of inhomogeneous magnetoactive plasma	337
Introduction. Some estimates	337
The approximate solution	338
Results of the calculation	343
§ 27. The behaviour of the wave field and the coefficients of reflection and transmission when the refractive index has singularities	345
Introduction. Singularities (poles) of the refractive index	345
The rigorous solution for a layer with $\varepsilon'_{\text{eff}} = g/(z+is)^2$	347
The rigorous solution for a layer with $\varepsilon'_{\text{eff}} = g^2/(z+is)$. The physical interpretation	347
A layer with $\varepsilon'_{\text{eff}} = g_1^2 + g_2^2/(z+is)$	349
The pole of the function $(n - i\kappa)_{1,2}^2$ in a magnetoactive plasma	351
The mechanism of resonance. The “peaking” of the field in a magnetoactive plasma	354
The Earth's ionosphere	356
The allowance for spatial dispersion and non-linear effects	357
§ 28. The “tripling” of reflected signals by the interaction of normal waves for small α	357
The range of small angles α between the magnetic field and the wave vector. Description of the phenomenon	357
Solution by the perturbation method for very small α	360
The variational method: second limiting case	366
The method of phase integrals	374
General results for $u = \omega_H^2/\omega^2 < 1$	375
Formulae for δ_0 . Allowance for collisions	377
The results for $u = \omega_H^2/\omega^2 > 1$	382
§ 29. Waves obliquely incident on a layer. The reciprocity theorem	385
Introduction	385
The approximation of geometrical optics	386
The field in the first approximation of geometrical optics	388
Graphs of the functions $q_{1,2}(v)$	390
The paths of the wave normals and rays	394
Some special cases	398
Penetration of waves and the “tripling” of signals for oblique incidence	401
Penetration of waves with $u = \omega_H^2/\omega^2 > 1$	403
Proof of the reciprocity theorem	404
The generalisation to the case of a magnetoactive medium	405
Media with an unsymmetrical tensor μ'_{ij} and with spatial dispersion	406

VI. REFLECTION OF RADIO WAVES FROM IONOSPHERIC LAYERS	408
§ 30. Introduction. Reflection from an arbitrary smooth layer	408
Propagation of radio waves in the ionosphere	408
Parameters of the ionosphere	409
Reflection of waves from an arbitrary layer	412
The effective height of reflection z_a . Height-frequency characteristics	416
A parabolic layer	418
Allowance for the variation of the layer with time. The Doppler effect	421
§ 31. Allowance for absorption	423
The effect of absorption on reflection of waves	423
The reflection coefficient when absorption is small. Determination of ν_{eff} from measurements of absorption	425
§ 32. The field structure near the reflection point	427
The field structure	427
The approximation of geometrical optics	430
Allowance for absorption	431
§ 33. Reflection and penetration of waves with nearly the critical frequency in a layer	432
A parabolic layer	432
An arbitrary layer	433
Allowance for absorption	437
The effective height for a parabolic layer (exact solution)	438
The time to establish the signal amplitude	441
§ 34. Reflection of obliquely incident waves	442
The reflection point. The critical frequency	442
The ray treatment	442
Theorems giving relations between the group paths for oblique and normal incidence	446
Reflection from a spherical layer	449
The field strength in signals reflected from the ionosphere	450
§ 35. Wave reflection with allowance for the effect of a magnetic field	454
The effect of a magnetic field. Critical frequencies	454
The wave phase and the reflection coefficient. The course of the rays	455
Quasilongitudinal and quasitransverse propagation	460
Oblique incidence	462
Allowance for the non-uniformity of the Earth's magnetic field	462
VII. RADIO WAVE PROPAGATION IN COSMIC CONDITIONS	464
§ 36. Propagation of radio waves in the Sun's atmosphere	464
Introduction	464
The solar corona	465
Propagation of radio waves in the corona	466
Emission of radio waves. Allowance for refraction	473
The equation of transfer. The effective temperature of the radio emission	475
The effect of the magnetic field	478
Transformation of plasma waves into radio waves	482
Collisionless absorption	483
Kirchhoff's law in a magnetoactive plasma	484

§ 37. Propagation of radio waves in the interstellar medium	486
Absorption of radio waves in the interstellar gas: general remarks	486
Calculation of the absorption coefficient in a highly rarefied plasma	488
Rotation of the plane of polarisation of radio waves in the interstellar medium	492
VIII. NON-LINEAR PHENOMENA IN A PLASMA IN A VARIABLE ELECTROMAGNETIC FIELD	495
§ 38. Introduction. A plasma in a strong electric field	495
Non-linear effects in a plasma with and without collisions	495
The condition for the field in the plasma to be weak. Some examples	496
Statement of the problem for a strong field	498
The elementary theory	498
The accuracy of the results of the elementary theory	505
The kinetic theory	506
A strongly ionised plasma	509
A weakly ionised plasma	511
The change in electron density by plasma heating in a non-uniform field	513
§ 39. Non-linear effects in radio wave propagation in the ionosphere	515
Introduction	515
Basic relations	516
The self-interaction effect	517
Non-linear interaction of waves. Cross-modulation	521
Non-linear interaction of unmodulated waves. Combination frequencies	525
The effect of radio waves on the ionosphere	528
Non-linearity due to changes in electron density	528
REFERENCES	531
INDEX OF SUBJECTS	601
INDEX OF NAMES	605
OTHER TITLES IN THE SERIES	617