

# Contents

Preface	xi
Preface to the English Edition	xvii
Chapter 1. Kinetic and Hydrodynamic Methods of Describing a Plasma	1
1.1. Kinetic equations hierarchy	1
1.1.1. Screened Coulomb interaction and the existence of plasma oscillations	1
1.1.2. Many-particle distribution functions and correlation functions	4
1.1.3. Chain of equations for many-particle functions	6
1.2. The Vlasov equation	8
1.2.1. The plasma parameter	8
1.2.2. The self-consistent field	9
1.2.3. Set of kinetic equations with self-consistent fields for a multi-component plasma	11
1.3. The pair correlation function of an equilibrium plasma and the Landau collision integral	11
1.3.1. The pair correlation function	11
1.3.2. Landau collision integral	16
1.4. Relaxation of a plasma	19
1.4.1. Relaxation time of a plasma	19
1.4.2. The equalization of the electron and ion temperatures	21
1.4.3. Boltzmann's $H$ -theorem for a quiescent plasma	22
1.5. The hydrodynamical description of a plasma	25
1.5.1. The hydrodynamical description	25
1.5.2. The equations of magneto-hydrodynamics	27
1.5.3. Transition from the kinetic to the hydrodynamical description	32
1.5.4. Two-component hydrodynamics	37
1.5.5. Generalized Ohm law	42
Chapter 2. Small Amplitude Magneto-hydrodynamic Waves	48
2.1. Magneto-sound and Alfvén waves	48
2.1.1. Phase velocities and polarization	48
2.1.2. Polars	53
2.1.3. Conical refraction	56
2.1.4. Damping of magneto-hydrodynamic waves	59
2.1.5. Excitation of magneto-hydrodynamic waves	61
2.1.6. Evolution of a perturbation	66
2.2. Characteristics of the magneto-hydrodynamical equations	71
2.2.1. Characteristic lines	71
2.2.2. Characteristic surfaces	75
2.2.3. Characteristics of stationary flow	78
Chapter 3. Simple Waves and Shock Waves in Magneto-hydrodynamics	83
3.1. Simple waves	83
3.1.1. The connection between simple waves and small amplitude waves	83
3.1.2. Kinds of simple waves	85
3.1.3. Distortion of the profile of a simple wave	87

## CONTENTS

3.1.4.	Integration of the equations for simple waves	91
3.1.5.	Riemann invariants	95
3.1.6.	Friedrichs' theorem	97
3.2.	Discontinuities	99
3.2.1.	Boundary conditions	99
3.2.2.	Classification of discontinuities	102
3.2.3.	Zemplén's theorem	107
3.2.4.	Simple and shock waves in relativistic magneto-hydrodynamics	109
3.3.	Stability and structure of shock waves	115
3.3.1.	Evolutionarity of shock waves	115
3.3.2.	Structure of the shock waves	121
3.3.3.	Oscillatory structure of a shock wave when there is a magnetic field present	127
3.3.4.	Cases of degeneracy	132
3.3.5.	Exothermic and endothermic discontinuities	138
3.3.6.	Sweeping-out conditions	146
3.4.	Study of discontinuities	150
3.4.1.	Discontinuities in various quantities	150
3.4.2.	Order of sequence of waves	154
3.4.3.	The piston problem	157
3.4.4.	Splitting-up of a discontinuity	162
3.4.5.	The Chapman-Jouguet theorem	164
3.4.6.	Oblique shock waves	167
Chapter 4.	High-frequency Oscillations in an Unmagnetized Plasma	171
4.1.	Hydrodynamical theory of high-frequency oscillations of an unmagnetized plasma	171
4.1.1.	Electromagnetic waves in a plasma	171
4.1.2.	Langmuir oscillations	176
4.1.3.	Ion-sound oscillations	178
4.2.	Kinetic theory of longitudinal plasma oscillations	181
4.2.1.	Evolution of an initial perturbation	181
4.2.2.	Frequency and damping of Langmuir oscillations	189
4.2.3.	The meaning of Landau damping	194
4.2.4.	Kinetic theory of ion-sound oscillations	196
4.3.	Kinetic theory of electromagnetic waves in a plasma	198
4.3.1.	The dielectric permittivity tensor and the dispersion equation for electromagnetic waves in a uniform plasma	198
4.3.2.	Polarization of plasma waves	203
4.3.3.	Excitation of waves in a plasma	204
4.3.4.	The dielectric permittivity tensor in the case of an isotropic particle distribution	206
Chapter 5.	Oscillations of a Plasma in a Magnetic Field	211
5.1.	Hydrodynamical theory of oscillations of a plasma in a magnetic field	211
5.1.1.	Dielectric permittivity tensor of a cold plasma in a magnetic field	211
5.1.2.	Plasma (hybrid) resonances in a cold plasma	214
5.1.3.	General picture of the spectra of the oscillations of a cold magneto-active plasma	217
5.1.4.	High-frequency (electronic) branches of the oscillations in a cold magneto-active plasma	219
5.1.5.	Low-frequency branches of the oscillations of a cold magneto-active plasma	221
5.1.6.	Propagation of electromagnetic waves in a cold magneto-active plasma parallel to the magnetic field	222
5.1.7.	Transverse propagation of electromagnetic waves in a cold magneto-active plasma	224
5.2.	Kinetic theory of plasma oscillations in a magnetic field	225
5.2.1.	Dielectric permittivity tensor in a magneto-active plasma in the kinetic approximation	225
5.2.2.	The dielectric permittivity tensor of a plasma with a Maxwell distribution	230
5.2.3.	Kinetic theory of plasma resonances	231

## CONTENTS

5.3.	Damping of high-frequency electromagnetic waves in a magneto-active plasma	237
5.3.1.	Electron-cyclotron absorption of the extra-ordinary wave in a hot low-density plasma	237
5.3.2.	Electron-cyclotron absorption of the slow extra-ordinary wave and of the ordinary wave in a high-density plasma	239
5.3.3.	Electron-cyclotron resonance at higher harmonics and electron Cherenkov damping of high-frequency waves	242
5.3.4.	Damping of waves near plasma resonances	244
5.4.	Absorption of Alfvén and fast magneto-sound waves	246
5.4.1.	Cherenkov absorption of Alfvén and fast magneto-sound waves in a low-pressure plasma	246
5.4.2.	Ion-cyclotron resonance	250
5.5.	Low-frequency oscillations of a hot plasma in a magnetic field	253
5.5.1.	Longitudinal oscillations of a plasma with hot electrons and cold ions	253
5.5.2.	Low-frequency electromagnetic waves in a plasma with finite pressure and $T_e \gg T_i$	258
5.5.3.	High-frequency electron sound	264
5.5.4.	Low-frequency electron sound	265
5.6.	Cyclotron waves in a plasma for the case of quasi-transverse propagation	267
5.6.1.	Longitudinal ion-cyclotron oscillations in a plasma for quasi-transverse propagation	267
5.6.2.	Non-potential ion-cyclotron waves in an isothermal low-pressure plasma for the case of quasi-transverse propagation	271
5.7.	Cyclotron waves in the case of transverse propagation	275
5.7.1.	Ordinary cyclotron waves	275
5.7.2.	Longitudinal electron-cyclotron oscillations	278
5.7.3.	Longitudinal ion-cyclotron oscillations	281
5.7.4.	Extra-ordinary electron-cyclotron waves	282
5.7.5.	Extra-ordinary ion-cyclotron waves	284
Chapter 6.	Interaction Between Charged Particle Beams and a Plasma. Stable and Unstable Particle Distributions in a Plasma	288
6.1.	Interaction of charged particle beams with the oscillations of an unmagnetized plasma	288
6.1.1.	Dispersion equation for a beam-plasma system	288
6.1.2.	Excitation of longitudinal plasma oscillations by resonance beam particles	291
6.1.3.	Excitation of longitudinal oscillations by a monoenergetical beam	293
6.1.4.	Instability of a plasma in which the electrons move relative to the ions	298
6.1.5.	Excitation of electromagnetic waves in a plasma by charged particle currents	302
6.1.6.	Instability of a plasma with an anisotropic velocity distribution	307
6.2.	Interaction of a charged particle beam with plasma oscillations in a magnetic field	309
6.2.1.	The dielectric permittivity tensor of a beam-plasma system in a magnetic field	309
6.2.2.	Excitation of longitudinal oscillations of a plasma in a magnetic field by an electron beam	311
6.2.3.	Instability of a magneto-active plasma in the field of a low-frequency electromagnetic wave	316
6.2.4.	The excitation of fast magneto-sound and Alfvén waves by electron and ion beams	321
6.3.	Excitation of electromagnetic waves in a plasma by oscillator beams	325
6.3.1.	Dielectric permittivity tensor of an oscillator beam-plasma system	325
6.3.2.	Excitation of longitudinal high-frequency oscillations by an electron oscillator beam	328
6.3.3.	Excitation of fast magneto-sound waves and Alfvén waves by oscillator beams	331
6.4.	Excitation of electromagnetic waves in a plasma by relativistic charged particle beams	333
6.4.1.	The dielectric permittivity tensor of a relativistic plasma beam	333
6.4.2.	Excitation of electromagnetic waves in an unmagnetized plasma by a relativistic electron beam	338
6.4.3.	Dispersion equation for "oblique" wave propagation	340
6.4.4.	Transverse propagation	343
6.5.	General criteria for the stability of particle distributions in a plasma	345
6.5.1.	Criteria for the stability or instability of particle distributions in an unmagnetized plasma	345

## CONTENTS

6.5.2.	Two-stream instability	349
6.5.3.	Stability criteria for electron distributions in a plasma in a magnetic field	351
6.6.	Absolute and convective instabilities	354
6.6.1.	Criteria for absolute and convective instability	354
6.6.2.	The travelling waves method	359
6.6.3.	Criterion for amplification and blocking of oscillations	360
6.6.4.	Sturrock's rules	361
6.6.5.	Global instability	367
6.6.6.	Non-invariant nature of the concepts of absolute and convective instabilities	370
6.6.7.	Nature of the beam instability	371
<b>Chapter 7.</b>	<b>Oscillations of a Partially Ionized Plasma</b>	<b>374</b>
7.1.	Electron distribution function and high-frequency electron oscillations in an external electrical field	374
7.1.1.	The kinetic equation	374
7.1.2.	Stationary electron distribution function	378
7.1.3.	High-frequency electron oscillations	381
7.2.	Ion-sound oscillations in a strong electrical field	383
7.2.1.	Ion-sound oscillations in the absence of an external magnetic field	383
7.2.2.	Ion-sound oscillations in external electrical and magnetic fields	385
7.3.	Low-frequency oscillations of a partially ionized plasma	387
7.3.1.	Oscillations involving non-conservation of the numbers of particles of the different components of the plasma	387
7.3.2.	Large amplitude uniform low-frequency oscillations	391
<b>References</b>		<b>393</b>
<b>Glossary</b>		<b>405</b>
<b>Index</b>		<b>409</b>
<b>Other Titles in the Series in Natural Philosophy</b>		<b>413</b>

### **Contents of Volume 2 Non-linear Theory and Fluctuations**

<b>Chapter 8.</b>	<b>Non-linear Waves in a Collisionless Plasma</b>
8.1.	Non-linear high-frequency waves in a cold plasma
8.2.	Non-linear waves in an unmagnetized two-temperature plasma
8.3.	Non-linear waves in an unmagnetized non-equilibrium plasma
8.4.	Non-linear waves in a magneto-active plasma with hot electrons
8.5.	Non-linear low-frequency waves in a cold plasma in a magnetic field
<b>Chapter 9.</b>	<b>Theory of Plasma Oscillations in the Quasi-linear Approximation</b>
9.1.	Quasi-linear theory of the oscillations of an unmagnetized plasma
9.2.	Quasi-linear theory of the oscillations of a magneto-active plasma
<b>Chapter 10.</b>	<b>Non-linear Wave-Particle Interactions</b>
10.1.	Kinetic equation for the waves
10.2.	Turbulent processes in which Langmuir waves take part.
10.3.	Ion-sound turbulence
10.4.	Interaction between magneto-sound and Alfvén waves
<b>Chapter 11.</b>	<b>Fluctuations in a Plasma</b>
11.1.	Fluctuation-dissipation relation
11.2.	Electromagnetic fluctuations in an equilibrium plasma
11.3.	Transformation of the fluctuation-dissipation relation
11.4.	Electromagnetic fluctuations in a non-isothermal plasma
11.5.	Electromagnetic fluctuations in a non-equilibrium plasma
11.6.	Kinetic theory of fluctuations
11.7.	Fluctuations in a partially ionized plasma in an external electrical field

## CONTENTS

### Chapter 12. Scattering and Transformation of Waves in a Plasma

- 12.1. Scattering of electromagnetic waves in an unmagnetized plasma
- 12.2. Transformation of transverse and longitudinal waves in a plasma
- 12.3. Incoherent reflection of electromagnetic waves from a plasma
- 12.4. Scattering and transformation of waves in a plasma in a magnetic field
- 12.5. Scattering and transformation of waves in a partially ionized plasma in an external electrical field
- 12.6. Scattering and transformation of waves in a turbulent plasma
- 12.7. Echoes in a plasma

### Chapter 13. Scattering of Charged Particles in a Plasma

- 13.1. The passage of charged particles through an unmagnetized plasma
- 13.2. Dynamic friction and diffusion coefficients in a plasma
- 13.3. Passage of charged particles through an equilibrium plasma in a magnetic field
- 13.4. The interaction of charged particles with a non-equilibrium plasma