

Contents

Preface 1

Chapter 1

Fundamentals

1. Introduction 3

1.1. The origin and nature of magnetohydrodynamics and
plasmadynamics. 3
1.1.1. The plasma state 6

1.2. Microscopic and macroscopic representations of a plasma . . . 8
1.2.1. The requirements for a statistical theory 12
1.2.2. Physical and ideal ensembles. 14

1.3. The mathematical foundations of the theory. 16
1.3.1. Measures. 17
1.3.2. Measurable functions and integration. 19
1.3.3. Distribution 20
1.3.4. Probability 22
1.3.5. Distribution functions 26

1.4. Conservation 28
1.4.1. Principles of mechanics. 30
1.4.2. External and internal forces. 33
1.4.3. Explicit forms of the Lagrangian. 36
1.4.4. Macroscopic conservation laws 37

1.5. Quantum theoretical formulation	39
1.5.1. The need for the quantum theory	40
1.5.2. Nature and properties of physical particles	42
1.5.3. Quantum mechanical ensembles	44
1.5.4. Conservation laws in quantum mechanics	45
1.5.5. The density matrix.	49
1.5.6. Quantum statistics and spin	51
1.6. Constants of the motion	53
1.6.1. Invariants of contact	55
1.6.2. Additivity	58
1.6.3. Liouville's theorem	60
1.6.4. Formulation of Liouville's equation	61
1.6.5. Equilibrium	63
1.6.6. Composite systems with constraints	64
References	66

Chapter 2

Introduction to electromagnetic fields

2. Electromagnetic theory	67
2.1. Physical basis of Maxwell's equations.	68
2.1.1. Charge density, field intensity, Coulomb's law, and electrostatics	69
2.1.2. Magnetic induction and magnetostatics	73
2.1.3. Stationary dielectrics, polarization, displacement,	76
2.1.4. Stationary magnetic media, magnetic intensity magnetization	79
2.1.5. Displacement currents and "magnetodynamics"	81
2.1.6. Electromagnetic induction and the Maxwell equations	82
2.1.7. Current and Ohm's law	84

2.2. Special fields and potential theory	87
2.2.1. Point charges and dipoles	87
2.2.2. Line, surface, and volume charges and dipoles	90
2.2.3. Magnetostatic fields, magnetic potentials and magnetic moments	97
2.2.4. Potential theory	102
2.2.5. Separation of variables and Bessel's functions	111
2.2.6. Energy	113
2.2.7. Electromagnetic potentials	120
2.3. Quasi-stationary theory.	123
2.3.1. "Lumped circuits"	124
2.3.2. Maxwellian theory of the "transmission line"	129
2.3.3. Homopolar generator	133
2.4. Waves and Fourier analysis	134
2.4.1. Plane solutions and plane waves in dielectrics	135
2.4.2. Conducting media	138
2.4.3. Reflection and refraction at surfaces	140
2.4.4. Group velocity and wave packets	142
2.4.5. Dispersion and impedance	144
2.4.6. Inhomogeneous wave equations	148
2.5. Hertz potentials, multipole expansions, and radiation fields	150
2.5.1. Hertz vectors	251
2.5.2. Spherical harmonics	152
2.6. Interaction of charged particles	158
2.6.1. Liénard-Wiechert potentials and the field of a moving particle.	159
2.6.2. Motion in external fields	161
2.6.3. Drift analysis	172
2.6.4. Approximate invariants	176
2.6.5. Radiation reaction.	183
2.6.6. Debye screening and motion of a particle in a plasma	190
References	193

Chapter 3

Fluid mechanics

Introduction

3.1. The state of a fluid	195
3.1.1. Densities	195
3.1.2. Flux densities	196
3.2. The conservation laws	199
3.2.1. Conservation of mass	199
3.2.2. Conservation of momentum.	201
3.2.3. Conservation of angular momentum	203
3.2.4. Conservation of energy	205
3.3. Conditions for equilibrium	207
3.3.1. Definition of a fluid	210
3.3.2. Equilibrium of composite systems	210
3.3.3. Temperature	211
3.3.4. Absolute temperature	213
3.3.5. Entropy of a simple fluid	216
3.3.6. Chemical potentials	219
3.3.7. Entropy of a fluid mixture	221
3.3.8. Equilibrium in a field of force	223
3.3.9. Surface effects.	225
3.4. Irreversible processes in fluids	228
3.4.1. Diffusion	230
3.4.2. Viscosity	232
3.4.3. Thermal conduction	232
3.4.4. The non-conservation of entropy	234
3.4.5. Boundary conditions	237
3.5. General results	241
3.5.1. Vorticity	343
3.5.2. Bernoulli's theorem	245
3.5.3. Approximation of reversibility.	245

3.6. Propagation and absorption of sound.	246
3.6.1. Velocity of sound	248
3.6.2. Absorption of sound by viscosity	250
3.6.3. Absorption due to thermal conduction	252
3.7. Shock waves	253
3.7.1. The Rankine-Hugoniot relations.	255
3.7.2. Structure of the shock zone	257
References	259

Chapter 4

Advanced electromagnetism

1. Introduction	260
4.1. Special relativity.	260
4.1.1. Lorentz transformations	261
4.1.2. Velocity	268
4.1.3. Momentum, energy, force	272
4.1.4. Photons	279
4.1.5. Relativistic hydrodynamics and thermodynamics.	283
4.1.6. Properties of an ideal relativistic fluid.	287
4.2. Electromagnetism as a relativistic theory	289
4.2.1. Point-sources in vacuum	290
4.2.2. Transformation rules.	293
4.2.3. Energy-momentum-force	295
4.2.4. Electromagnetism in simple linear media	299
4.2.5. Motion of a particle in a field	302
4.2.6. Four-dimensional Fourier analysis of fields	305
4.2.7. Variational principles of electromagnetism	308
4.3. Electromagnetic waves	310
4.3.1. Cavity resonators	311

4.3.2. Wave guides	317
4.3.3. The dipole theory of waves in dielectrics	321
4.3.4. Waves in magnetized plasma	323
4.3.5. Slow wave structures	328
4.4. Radiation of moving charges	333
4.4.1. Field of a particle in uniform and accelerated motion	333
4.4.2. Quadrupole radiation	339
4.4.3. The electron theory of Lorentz: Absorption and scattering.	341
4.4.4. The electron theory of Lorentz: Partial fields, dispersion and polarization.	347
4.4.5. Relativistic radiation reaction	351
4.5. Magnetohydrodynamics	354
4.5.1. Fundamental equations of magnetohydrodynamics	354
4.5.2. The conservation laws of magnetohydrodynamics	356
4.5.3. The equilibrium of a plasma.	358
4.5.4. Constitutive equations for slowly varying weak fields	362
4.5.5. Ohm's law and thermoelectric effects	366
4.5.6. Theory of conduction and thermoelectricity	369
4.5.7. Formalism for strong fields	376
4.5.8. Thermodynamic functions of gaseous plasma	380
4.5.9. Partial momentum conservation and Spitzer's formula	381
References	383

Chapter 5

Molecular theory of fluids

5. Introduction	385
5.1. Molecular structure	387
5.1.1. Intermolecular forces.	387
5.1.2. Structure of monatomic fluids	389

5.1.3. Molecular orientation and structure	393
5.1.4. Velocity distributions	394
5.1.5. Average values	396
5.2. The transport of momentum and energy	398
5.2.1. Momentum flux.	399
5.2.2. Energy flux	402
5.3. Surface phenomena	404
5.3.1. Properties of the Gibbs surface	405
5.3.2. Method of determination of the surface tension	407
5.4. Statistical mechanics of equilibrium	408
5.4.1. Densities and distribution functions	410
5.4.2. Results for equilibrium	414
5.4.3. Velocity distributions in equilibrium	417
5.4.4. Equilibrium of systems in limited contact	419
5.4.5. Statistical mechanics of an ideal gas	420
5.4.6. Thermodynamical relations	423
5.4.7. Summary of results	424
5.4.8. Application to imperfect gases.	428
5.5. Computational methods	433
5.5.1. The Monte Carlo method.	433
5.5.2. The method of integral equations	437
5.6. Statistical mechanics of irreversible processes	440
5.6.1. Solutions of Liouville's equation.	445
5.6.2. Kinetic theory of fluids.	449
5.6.3. The general expansion procedure	454
5.6.4. The transport coefficients.	460
5.6.5. Computational procedure.	468
References	472

Appendix 1

Measure, probability, and statistical mechanics

A1.1. Sets, numbers, Euclidean volume	473
A1.2. General measure and integration.	477
A1.3. Probability in classical physics.	481
A1.4. Random variables, independence, and laws of large numbers	485
A1.5. Distributions and characteristic functions	492
A1.6. Special distributions and limits	497
A1.7. Conditional concepts and stochastic processes	505
A1.8. Statistical mechanics and thermodynamics	513

Appendix 2

Linear spaces, vectors, matrices, tensors

A2.1. Linear spaces and vectors.	534
A2.2. Matrices	535
A2.3. Tensors	537
A2.4. Tensor differentiation	540

Appendix 3

Fourier analysis and Schwartz distributions

A3.1. Functions of bounded variation	543
A3.2. Fourier analysis	544
A3.3. Fourier series and transforms	546
A3.4. Schwartz distributions	550
A3.5. Examples of distributions.	552
A3.6. Operations and representations	555
A3.7. Fourier transforms of distributions.	556

Appendix 4

Vector analysis

A4.1. Rectangular coordinates	558
A4.2. Vector integration	559
A4.3. Curvilinear coordinates.	561
A4.4. Special coordinate systems	563

Appendix 5

Differential equations

A5.1. Ordinary differential equations – initial value problem . . .	569
A5.2. Boundary value problems, Green’s function	572
A5.3. Integral equations and linear operators	577
A5.4. Partial differential equations	582
A5.5. Hyperbolic systems	587

Appendix 6

Calculus of variations

A6.1. Calculus of variations	592
--	-----

Appendix 7

Thermodynamics

A7.1. The “First law”	598
A7.2. Carathéodory’s principle and absolute temperature.	599
A7.3. Carathéodory’s principle and fluid mixtures	601
A7.4. Characteristic functions	604

Appendix 8

Units and dimensions

A8.1. Units	608
A8.2. Dimensional analysis.	609
References	613
Subject index	616