Contents

PREFACE vii

1 THE HISTORY AND CHARACTER OF MAGNETOHYDRODYNAMICS (MHD) 1

2 THE MHD APPROXIMATION 9

2.1 The continuum approximation — 2.2 The electrical properties of the fluid — 2.3 The electric and magnetic fields — 2.4 Action at a distance — 2.5 Moving axes — 2.6 Conducting material — 2.7 The low-frequency approximation — 2.8 Fluid-mechanical aspects — 2.9 Energetic aspects of MHD — 2.10 Magnetic energy — Problems

3 THE KINEMATIC ASPECT OF MHD 31

3.1 Formulation of the problem — 3.2 The analogy with vorticity — 3.3 Diffusion alone — 3.4 Convection alone (perfectly conducting fluid) — 3.5 A note on moving fields — 3.6 Convection and diffusion together — 3.7 High magnetic Reynolds number — 3.8 Low magnetic Reynolds number — 3.9 The dynamo problem — 3.10 A note on "field-sweeping" — 3.11 Ferraro's law of isorotation — 3.12 Two-dimensional kinematic problems — 3.13 Two-dimensional case with flow only in the direction of no variation — 3.14 Two-dimensional case with the field in the direction of no variation — 3.15 Two-dimensional case with the current flow (but no field) in the direction of no variation — Problems

4 THE MAGNETIC FORCE AND ITS EFFECTS 60

4.1 The magnetic force and the inertia force — 4.2 Equivalent stress systems — 4.3 Control volume statements — 4.4 Principal directions and stresses — 4.5 Some applications of Maxwell and inertia stresses — 4.6 Magnetohydrostatics — 4.7 The linear pinch — 4.8 The theta-pinch — 4.9 Force-free fields — 4.10 The magnetic force in moving fluids — 4.11 Kelvin's theorem and vorticity — 4.12 The case of irrotational force per unit mass — 4.13 Vorticity suppression — 4.14 Vorticity creation — 4.15 Vorticity propagation — 4.16 Conclusion — Problems

5 BOUNDARY AND EXTERNAL CONDITIONS 113

5.1 The setting-up of MHD problems — 5.2 The linkage problem — 5.3 The induced-field problem in a channel flow — 5.4 Boundary conditions in time — 5.5 Boundary conditions in space — 5.6 Boundary conditions on velocity — 5.7 Boundary conditions on magnetic field — 5.8 Boundary conditions on current — 5.9 Boundary conditions on electric field — 5.10 Boundary conditions that arise from a balance of forces — 5.11 Thermodynamic and other boundary conditions — Problems

6 LINEAR MAGNETOHYDRODYNAMICS 140

6.1 The nature of linear MHD — 6.2 One-dimensional problems — 6.3 Two-dimensional problems — 6.4 One-dimensional problems with v_x zero — 6.5 Steady Hartmann flows — 6.6 Linear Alfvén waves — 6.7 Harmonic Alfvén waves with ohmic damping — 6.8 One-dimensional harmonic motions with v_x zero, σ and η non-zero and finite — 6.9 Pulsed motions with v_x zero, σ and η non-zero: the MHD Rayleigh problem — 6.10 Steady one-dimensional problems with v_x non-zero — 6.11 Two-dimensional linear problems — 6.12 Steady laminar flow in a pipe under uniform transverse field — 6.13 Flow in a circular pipe with an axial current in the fluid — Problems

7 MAGNETOGASDYNAMICS 184

7.1 Introduction — 7.2 The thermodynamics of the fluid — 7.3 Energy equations — 7.4 Entropy equations — 7.5 One-dimensional MGD under transverse magnetic fields — 7.6 Steady flow under arbitrary distributions of B_y and E_z — 7.7 Strictly one-dimensional steady MGD under a transverse field — 7.8 Perfectly conducting MGD under strictly transverse fields — 7.9 The MGD shock in a transverse field — 7.10 Strictly one-dimensional MGD with streamwise field components — 7.11 Plane weak (magneto-acoustic) waves — 7.12 MGD shocks with normal field components — 7.13 Strictly one-dimensional steady MGD with streamwise field components (ohmic diffusion dominant) — 7.14 Two-dimensional, non-dissipative MGD — 7.15 Magnetoacoustic waves — 7.16 Two-dimensional steady MGD flow without dissipation — 7.17 The aligned field case — Problems

NOMENCLATURE and a note on dimensionless groups in MHD 253 251

BIBLIOGRAPHY 255

INDEX 258