

Contents

1. Introduction to the Theory of Gasdynamic Shock Waves	1
1.1 Equations of Motion	3
1.1.1 Conservation Laws and the Euler Equation	3
1.1.2 Viscosity and Heat Transfer in a Fluid. The Navier-Stokes Equation	7
1.2 Kinetic Theory and Gasdynamic Equations	8
1.2.1 Kinetic Equations for a Gas	8
1.2.2 Obtaining the Gasdynamic Equations	9
1.3 Limits of Applicability of the Gasdynamic Equations in Studying Shock-Wave Structure	15
1.4 Linear and Nonlinear Waves	18
1.4.1 Linear and Sonic Waves	18
1.4.2 Nonlinear Plane Waves	21
1.4.3 The Riemann Invariants	23
1.4.4 Simple Waves	25
1.4.5 Expansion Waves	27
1.5 Origins of Discontinuities	30
1.5.1 Profile Distortion of a Running Wave	30
1.5.2 Breakdown of the Sonic Wave Front	32
1.5.3 Burgers' Equation. Evolution of Spectral Composition of the Sonic Wave	34
1.6 Discontinuities and Shocks	36
1.6.1 Discontinuous Solutions	36
1.6.2 The Solution of Burgers' Equation for the Profile of a Weak Shock Wave	39
1.6.3 The Shock Adiabats	40
1.6.4 Production of Shock Waves. Elementary Theory of a Shock Tube	44
1.7 Criteria of Stability and Evolutionarity of Discontinuities	47
1.7.1 Evolutionarity	47
1.7.2 Evolutionarity Condition and Existence of the Shock Structure. Basic and Additional Relations on the Front	53
1.7.3 Spectra of Dissipative Waves, Corresponding to Shock-Wave Structure Described by Burgers' Equation	58
1.7.4 Stability and Evolutionarity of Plane Discontinuities in Three Dimensions	62
1.8 Structures of Gasdynamic Shock Waves	66
1.8.1 Equations of the Shock Layer	66
1.8.2 Shock Structure Shaped by Viscosity Alone	68
1.8.3 Shock-Front Structure in a Gas with High Heat Conductivity	70
1.9 Detonation and Deflagration	77
1.9.1 Propagation of an Exothermal Reaction. Equations of Structure of the Reaction Zone	77

1.9.2	Structures of the Detonation and Deflagration Fronts	80
1.9.3	Realization of Different Propagation Regimes of the Reaction. The Piston Problem	86
2.	Gas Shock Ionization and Shock-Wave Structures in Plasmas	91
2.1	Shock Structures in a Completely Ionized Plasma	93
2.1.1	Equations for the Shock Layer and Boundary Conditions	93
2.1.2	Structure of a Weak Shock Wave	98
2.1.3	Structure of a Strong Shock Wave	101
2.1.4	Polarization of Plasma in Shock Waves	106
2.2	Shock Structure in a Plasma with Ionization	110
2.2.1	Shock-Layer Equations and Boundary Conditions	110
2.2.2	Shock Structure Associated with Multiple Ionization	120
2.2.3	Shock Structure in Partially Ionized Argon	125
2.3	Structure of an Ionizing Shock Wave	129
2.3.1	Morphology	129
2.3.2	Structure of the Precursor Region	134
2.3.3	Precursor Ionization in Electromagnetic Shock Tubes	142
2.3.4	Structure of the Ionization-Relaxation and Radiative Cooling Regions	145
2.4	Effects of Plasma Flow Nonunidimensionality in Ionizing Shock Waves	154
2.4.1	Effects of the Wall Boundary Layer in a Shock Tube on the Structure of the Relaxation Region	154
2.4.2	Instability of Ionizing Shock Waves	159
3.	Magnetohydrodynamic Shock Waves in Plasmas	163
3.1	Basic Equations	165
3.1.1	Magnetohydrodynamic Equations	165
3.1.2	Two-Fluid Transfer Equations for a Plasma	169
3.2	Magnetohydrodynamic Waves	173
3.2.1	Linear MHD Waves	173
3.2.2	Damping and Dispersion of Linear MHD Waves	176
3.2.3	Nonlinear Simple MHD Waves	179
3.3	Discontinuities and Shock Waves in Magnetohydrodynamics	184
3.3.1	Classification of Discontinuities	184
3.3.2	Boundary Conditions and the Shock Adiat in Magnetohydrodynamics	187
3.3.3	Evolutionarity Conditions for MHD Shock Waves	194
3.3.4	Shock Structures in the MHD Approximation	198
3.3.5	Evolutionarity of Singular MHD Shock Waves	203
3.4	Structures of Transverse Shocks	206
3.4.1	Boundary Conditions and the Shock Adiat	206
3.4.2	Structure of Transverse Shock Waves in Magnetized Plasmas	208
3.4.3	Structures of Transverse Shock Waves in Nonmagnetized and Partly Magnetized Plasmas	218
3.4.4	Plasma Polarization in Transverse Shock Waves	225
3.4.5	Experimental Investigations of Transverse Shock Waves in Plasma	229
3.5	Structures of Switch-On Shock Waves	232
3.5.1	Boundary Conditions and the Shock Adiat	232
3.5.2	Switch-On Shock-Wave Structures in Nonmagnetized Plasma	235
3.5.3	Switch-On Shock-Wave Structure in Magnetized Plasma	239
3.6	Structures of Switch-Off Shock Waves	248

4. Ionizing Shock Waves in Magnetic Fields: Structures and Stability	256
4.1 Classification and the Problem of Boundary Conditions	257
4.1.1 The Basic Boundary Conditions	257
4.1.2 Evolutionarity Conditions	259
4.2 Shock Structures and Additional Boundary Conditions	263
4.2.1 Magnetic Structures of Ionizing Shocks as $P_m \rightarrow 0$	263
4.2.2 The Criterion for Distinguishing Between Ionizing and MHD Shock Propagation Regimes	275
4.2.3 Precursor Ionization in a Magnetic Field. Conditions for the Ionization Stability of the Upstream Flow	277
4.2.4 Additional Boundary Conditions and the Magnetic Structures of Ionizing Shocks	282
4.2.5 Limiting Regimes	285
4.3 Transverse Ionizing Shock Waves	289
4.3.1 Magnetic Structures	289
4.3.2 Additional Boundary Conditions and Structures of Transverse Ionizing Shocks	294
4.3.3 Structure of Transverse MHD Shocks in Partially Ionized Plasma	298
4.4 Normal Ionizing Shock Waves	300
4.4.1 Magnetic Structures	300
4.4.2 Tensor Conductivity and Joule Heating of Plasmas in Normal Ionizing Shocks	307
4.4.3 Switch-On MHD Shocks in Partially Ionized Plasmas	313
4.5 Switch-Off Ionizing Shock Waves	316
 5. Dynamics of Shock Waves in Magnetic Fields	 321
5.1 Electromagnetic Shock Tubes	322
5.1.1 Design and Operation of Electromagnetic Shock Tubes	322
5.1.2 Elementary Theory of Electromagnetic Shock Tubes: The Snowplow Model	328
5.1.3 Effects of Nonunidimensionality of the Plasma Flow in Coaxial Electromagnetic Shock Tubes	334
5.2 Piston Problem	337
5.2.1 Self-Similar Magnetic Piston Problem in Magnetohydrodynamics	337
5.2.2 Self-Similar Piston Problem for Flows with Ionizing Shock Waves	345
5.3 Dynamics of Transverse Shocks in Magnetized Plasma	354
5.4 Evolution of the Initial Ionizing Discontinuity in the Transverse Magnetic Field	358
5.5 Shaping the Structure of the Normal Ionizing Shock	367
 References	 373
Subject Index	381