

Contents

Preface *XI*
Symbols, Constants and Electronic Symbols *XIII*

1	Plasma, an Overview	1
1.1	Introduction	1
1.2	Plasma	4
1.2.1	Space Plasmas	4
1.2.2	Kinetic Plasmas	4
1.2.3	Technological Plasmas	5
1.3	Classical Models	5
1.3.1	Simple Ballistic and Statistical Models	5
1.3.2	Statistical Behaviour	6
1.3.3	Collisions Between Particles	8
1.3.4	Coulomb Forces	9
1.3.5	Boundaries and Sheaths	10
1.3.6	Degree of Ionization	10
1.4	Plasma Resonance	11
1.5	The Defining Characteristics of a Plasma	11
	References	13
	Further Reading	13
2	Elastic and Inelastic Collision Processes in Weakly Ionized Gases	15
2.1	Introduction	15
2.2	The Drift Velocity	15
2.2.1	Electrical Conductivity	17
2.2.2	Mobility	17
2.2.3	Thermal Velocity	18
2.2.4	Collision Frequency	18
2.2.5	Collision Cross-section	19
2.3	Inelastic Collision Processes	21
2.3.1	Excitation	22
2.3.1.1	Metastable Processes	22

2.3.2	Ionization and Recombination Processes	23
2.3.2.1	Charge Transfer	24
2.3.2.2	Dissociation	24
2.3.2.3	Negative Ionization	24
2.3.2.4	Recombination	24
2.3.2.5	Metastable Ionization	25
	References	26
3	The Interaction of Electromagnetic Fields with Plasmas	29
3.1	Introduction	29
3.2	The Behaviour of Plasmas at DC and Low Frequencies in the Near Field	29
3.2.1	Charged Particles in Electromagnetic Fields	31
3.2.1.1	Behaviour of a Charged Particle in an Oscillating Electric Field	32
3.2.1.2	Plasma Frequency	34
3.2.1.3	The Debye Radius	35
3.3	Behaviour of Charged Particles in Magnetic Fields (Magnetized Plasmas)	37
3.4	Initiation of an Electrical Discharge or Plasma	41
3.5	Similarity Conditions	41
	References	43
	Further Reading	43
4	Coupling Processes	45
4.1	Introduction	45
4.2	Direct Coupling	45
4.2.1	The Cathode	49
4.2.1.1	Emission Processes	51
4.2.2	The Cathode Fall Region	56
4.2.3	The Anode	57
4.2.4	The Discharge Column	57
4.2.5	Interaction of Magnetic Fields with a Discharge or Plasma	59
4.3	Indirect Coupling	62
4.3.1	Induction Coupling	62
4.3.2	Capacitive Coupling	64
4.3.3	Propagation of an Electromagnetic Wave	65
4.3.4	The Helical Resonator	68
4.3.5	Microwave Waveguides	69
4.3.6	Electron Cyclotron Resonance	70
4.3.7	The Helicon Plasma Source	74
	References	75
	Further Reading	75

5	Applications of Nonequilibrium Cold Low-pressure Discharges and Plasmas	77
5.1	Introduction	77
5.2	Plasma Processes Used in Electronics Fabrication	77
5.2.1	The Glow Discharge Diode	80
5.2.2	The Magnetron	83
5.2.3	Inductively Coupled Plasmas	84
5.2.4	Electron Cyclotron Resonance Reactor	85
5.2.5	The Helical Reactor	86
5.2.6	The Helicon Reactor	87
5.3	Low-pressure Electric Discharge and Plasma Lamps	88
5.3.1	The Low-pressure Mercury Vapour Lamp	88
5.3.2	Cold Cathode Low-pressure Lamps	91
5.3.3	Electrodeless Low-pressure Discharge Lamps	91
5.4	Gas Lasers	91
5.5	Free Electron and Ion Beams	94
5.5.1	Electron and Ion Beam Evaporation	94
5.5.2	Ion Beam Processes	95
5.5.3	High-power Electron Beams	97
5.6	Glow Discharge Surface Treatment	99
5.7	Propulsion in Space	100
	References	101
	Further Reading	101
6	Nonequilibrium Atmospheric Pressure Discharges and Plasmas	103
6.1	Introduction	103
6.2	Atmospheric Pressure Discharges	103
6.2.1	Corona Discharges	105
6.2.2	Corona Discharges on Conductors	108
6.3	Electrostatic Charging Processes	110
6.3.1	Electrostatic Precipitators	110
6.3.2	Electrostatic Deposition	113
6.4	Dielectric Barrier Discharges	114
6.5	Plasma Display Panels	116
6.6	Manufacture of Ozone	116
6.7	Surface Treatment Using Barrier Discharges	118
6.8	Mercury-free Lamps	118
6.9	Partial Discharges	118
6.10	Surface Discharges	120
	Further Reading	121
7	Plasmas in Charge and Thermal Equilibrium; Arc Processes	123
7.1	Introduction	123
7.2	Arc Welding	124
7.2.1	Metal Inert Gas Welding	126

7.2.2	Tungsten Inert Gas Welding	127
7.2.3	Submerged Arc Welding	129
7.2.4	The Plasma Torch	129
7.3	Electric Arc Melting	131
7.3.1	The Three-phase AC Arc Furnace	131
7.3.2	DC Arc Furnaces	134
7.3.3	Electric Arc Smelting	135
7.3.4	Plasma Melting Furnaces	136
7.3.5	Vacuum Arc Furnaces	137
7.4	Arc Gas Heaters	138
7.4.1	Inductively Coupled Arc Discharges	139
7.5	High-pressure Discharge Lamps	141
7.6	Ion Lasers	144
7.7	Arc Interrupters	145
7.7.1	Vacuum Circuit Breakers and Contactors	147
7.8	Magnetoplasmadynamic Power Generation	149
7.9	Generation of Electricity by Nuclear Fusion	149
7.10	Natural Phenomena	150
7.10.1	Lightning	150
	Further Reading	152
8	Diagnostic Methods	155
8.1	Introduction	155
8.2	Neutral Particle Density Measurement	155
8.3	Probes and Sensors	156
8.3.1	The Langmuir Probe	156
8.3.2	Magnetic Probes	158
8.4	Optical Spectroscopy	159
8.4.1	Optical Emission Spectroscopy	159
8.4.2	Absorption Spectroscopy	161
8.4.3	Scattering Measurements	161
8.5	Interferometry	162
8.5.1	Microwave Interferometer	163
8.6	Mass Spectrometry	164
8.7	Electrical Measurements	165
8.7.1	Electrical Instrumentation	166
8.7.2	The Oscilloscope	167
8.7.3	Electrical Measurements Using Probes	168
8.7.4	Current Measurement	170
	Further Reading	172
9	Matching, Resonance and Stability	173
9.1	Introduction	173
9.2	The Plasma Characteristic	173
9.3	Stabilizing Methods	176

9.3.1	Reactive Stabilization	176
9.4	Effect of Frequency	179
9.5	Interaction between the Plasma and Power Supply Time Constants	179
9.6	Matching	180
9.7	Resonance	182
9.8	Parasitic Inductance and Capacitance	183
	Further Reading	185
10	Plasma Power Supplies	187
10.1	Introduction	187
10.2	Transformers and Inductors	187
10.3	Rectification	191
10.4	Semiconductor Power Supplies	193
10.4.1	The Inverter Circuit	193
10.4.2	Semiconductor Switches	195
10.4.3	Current Control	195
10.4.4	The Inverter Circuit	196
10.4.5	Converter Circuits	197
10.4.6	Inverter Frequencies	198
10.4.7	High-Frequency Inverter	198
10.5	Electronic Valve Oscillators	199
10.6	Microwave Power Supplies	199
10.7	Pulsed Power Supplies	200
10.8	Ignition Power Supplies	201
10.9	Electromagnetic Interference	205
10.9.1	Conduction	206
	Further Reading	207
	Index	209

