

Contents

Preface	xiii
1 Introduction	1
1.1 What are dusty and dirty plasmas?	2
1.2 How to describe a new plasma regime of dusty and dirty plasmas?	2
1.2.1 Particle dynamics	2
1.2.2 Fluid dynamics	3
1.2.3 Kinetic (distribution function) approach	3
1.3 Features of dusty and dirty plasmas	4
1.4 New aspects of gravito-electrodynamics and EHD: electric reconnection and critical velocity	4
1.4.1 Two basic roles of dust in different environments	5
1.4.2 Why electric reconnection and critical ionization effects are so important?	5
1.5 Noise and chaos in dusty and dirty plasmas	5
1.6 Roles of HD, MHD, and EHD in neutral and ionized gases, dusty and dirty plasmas	7
1.7 EHD or EMHD and its relevance to atmospheric, cosmic, and laboratory dusty and dirty plasmas	8
<i>References</i>	9
2 Particle Dynamics of Dust: Gravito-Electrodynamics	10
2.1 Newtonian dynamics	11
2.2 Hamiltonian dynamics	12
2.3 Particle drifts: guiding center approach	14
2.3.1 $\mathbf{E} \times \mathbf{B}$ drift	14
2.3.2 Gravitational field drift	15
2.3.3 Grad- $\mathbf{B}$ drift	16
2.3.4 Curvature drift	17
2.3.5 Nonuniform $\mathbf{E}$ drift	18
2.3.6 Polarization drift	19
2.4 Magnetic moment	20
2.5 Magnetic mirrors and cusps	22
2.5.1 Acceleration of particles by magnetic mirrors: Fermi acceleration	23
2.5.2 Magnetic cusps	25
2.5.3 Van Allen belts and polar cusps and their comparison with laboratory mirror and cusp	25
2.5.4 Hybrid mirror-cusp device in the laboratory	27
2.6 Adiabatic invariants	29
2.6.1 The first adiabatic invariant: $J_{\perp}$	29
2.6.2 The second adiabatic invariant: $J_{\parallel}$	30
2.6.3 The third adiabatic invariant: Φ	31

2.7 Gravito-electrodynamics of interplanetary dust	31
<i>References</i>	34
3 Electric Cusp and Reconnection	35
3.1 Background and concept of electric cusp and reconnection	35
3.2 Electric cusp, potential, and field	36
3.3 Two consequences of dust or object related electric field line merging-reconnection	37
3.4 Electric potential and field for dust or object perturbation in an electric cusp	38
3.4.1 Grain as a point particle or charge	38
3.4.2 The electric potential in the presence of a point charge and a conducting spherical grain	39
3.4.3 The electric potential in the presence of a spherical grain and a quad-rupole and the induced grain surface charge	40
3.5 Electric force exerted on a conducting spherical dust in an electric cusp	41
3.5.1 Electric force exerted on a conducting spherical dust by a point charge q	41
3.5.2 Electric force exerted on a conducting spherical dust by a quad-rupole	42
3.6 Electric force exerted on a dielectric spherical grain in a nonuniform electric field	44
<i>References</i>	45
4 Electrodynamics and Gravito-Electrodynamics of Dust in an Electric Cusp or Mirror	47
4.1 Electrodynamics of uncharged dust near a cusp center in the ecliptic plane of a quadrupole	47
4.2 Nonlinear electrodynamics of uncharged dust placed in a quadrupole: electric mirrors	50
4.3 Particle acceleration and deceleration in electric mirrors formed by a quadrupole	53
4.4 Gravito-electrodynamics of dust in an electric cusp: effects of gravity	55
4.5 Applications to dust acceleration under horizontal electrification or thunderclouds and possible dust layer formation	56
4.5.1 Case of a single electric cusp with electric mirrors formed by a single horizontal dipole or double layer above a ground for Earth and Io	57
4.5.2 Case of vertically periodic electric-cusps with electric mirrors formed by a longitudinal sequence of horizontal dipoles or double layers	59
4.5.3 Relative importance of electric forces on an uncharged and a charged grain in an electric cusp or mirror	61
4.6 Three dimensional motion of an uncharged or charged particle not in the	

ecliptic plane of a quadrupole	62
4.7 Relevance of electric cusp and reconnection model to a variety of atmospheric, cosmic (interplanetary, interstellar), and laboratory phenomena	65
<i>References</i>	66
5 Critical Ionization Velocities	67
5.1 Alfvén's critical velocity	67
5.2 Critical velocity experiments for low pressure gases	68
5.3 Critical velocity theories for low pressure gases	70
5.4 Electron, ion, and atom critical velocities for critical ionization in collisional gases	70
5.5 Relation between critical velocities and gas discharges (streamer, leader, and main discharge or return stroke)	71
5.6 Estimates of streamer and leader velocities based on critical velocities and their comparison with observations	73
5.7 Relation between electron or ion drift and critical velocities	73
5.8 Relation between critical velocity ionization and beam plasma discharge	77
5.9 Relevance of critical velocity concept to various cosmic, atmospheric, and laboratory phenomena involving or accompanying ionizations	77
<i>References</i>	78
6 Joint Effects of Electric Reconnection and Critical Velocity Ionization for Collisional Gases	81
6.1 Roles of dust or object invading an electric cusp in electric reconnection for collisional gases	81
6.2 EHD flow or shock generation with the critical ionization velocity by electric reconnection	83
6.2.1 Uncharged (neutral) dust in an electric cusp	83
6.2.2 Charged dust in an electric cusp	83
6.2.3 A sharp object in an electric cusp	84
6.3 Rocket and tower triggered lightning	84
6.3.1 Electric cusp in winter thunderstorm configuration	85
6.3.2 Triggered processes by electric reconnection and critical velocity ionization	86
6.3.3 Bipolar lightning flash	89
6.3.4 Bi-directional leaders	91
6.4 Direct observational evidence of electric cusp and reconnection model	91
6.5 Basic studies associated with joint effects of electric reconnection and critical velocities: universal electric-cusp type plasma reactor	93
6.5.1 An example of DC operation	94
6.5.2 An example of AC (RF) operation	94
<i>References</i>	94

7 EHD and EMHD Transport Processes in a Charged One-Component Fluid: Single Fluid Model	96
7.1 EHD or EMHD equations of motion of a charged fluid: equations of continuity and conservation of momentum	96
7.2 Maxwell's equations in moving media	97
7.3 Equations of state	97
7.4 Fluid equations of motion in the HD regime: the Navier-Stokes equation	99
7.5 Fluid equations of motion in the MHD regime	99
7.6 Simplified EHD fluid equations of motion	100
7.7 Simple fluid equations of motion and the Boltzmann distribution	101
7.8 Equations of energy transport and heat transfer	101
7.9 Equations of fluid vorticity, magnetic, and electric field transport	103
7.10 The Kelvin-Helmholtz theorem and source-free frozen-in field concept	105
7.11 The electric Reynolds number and the space-charge related Kelvin-Helmholtz theorem with frozen-in field concept	106
7.12 A simplified equation of magnetic field transport in an external magnetic field in a dielectric fluid	109
7.13 Electric and space-charge field transport and electric reconnection	110
References	111
8 EHD or EMHD for Multi-Component Dusty Plasmas	112
8.1 EHD or EMHD equations for multi-component dusty plasmas: multi-fluid model	112
8.2 Basic features of tenuous three-component dusty plasmas	113
8.3 Electrostatic charging of dust for isolated grain ($a \ll \lambda_D \ll d$)	115
8.3.1 Grain potential in a thermal Maxwellian plasma	116
8.3.2 Grain potential in a non-Maxwellian plasma	116
8.3.3 Potential of grains drifting with respect to a plasma	117
8.3.4 Grain charging at higher electron energies	118
8.4 Electrostatic charging for grain ensemble ($a \ll d \ll \lambda_D$)	120
8.5 Physical effects of dust electrostatic charging	122
8.5.1 Coagulation	122
8.5.2 Disruption	123
8.5.3 Levitation	125
8.6 Plasma and other effects on gravito-electrodynamics of interplanetary and interstellar dust	125
8.6.1 Plasma drag	126
8.6.2 Radiation pressure: photon or Poynting-Robertson drag	126
8.6.3 Gyrophase drift	127
8.7 Waves in Dusty Plasmas	127
8.7.1 Motion of ion fluid	128
8.7.2 Motion of electron fluid	129
8.7.3 Motion of dust fluid	129
8.7.4 Ion waves	129
8.7.5 Dust acoustic waves	131

8.8 Plasma crystals	132
References	136
9 EHD Turbulence, Vortices, and Self-Organizations	140
9.1 Turbulent EHD	140
9.1.1 Equations for turbulent background	141
9.1.2 Averaged equations	142
9.1.3 Equations for additional fields of random fluctuations	142
9.1.4 Correlators of turbulent fields v^t , ρ^t , E^t , and B^t	143
9.1.5 Estimates of averaged equations	144
9.2 The equation of EHD vortices	145
9.3 Fluid vortex merging and electric reconnection	147
9.4 EHD vortices and tornadic thunderstorms	148
9.4.1 What are tornadoes?	148
9.4.2 Relevance of EHD vortices to tornadic thunderstorms	148
9.5 Two kinds of self-organization in EHD vortices	150
9.5.1 Self-organization to large-scale coherent structures with helical turbulence	150
9.5.2 Self-organization to coalescence of fluid vortex and electric field lines	150
9.6 Chaos and order	151
9.7 Relation between electric, magnetic, and fluid vortex merging-reconnection	152
9.8 Some additional studies related to EHD/EMHD, self-organization, chaos, fractals, turbulence, and vortices	154
References	158
10 Dust in Space and in the Laboratory Including Further Examples of Electric Reconnection and Critical Velocity Ionization	161
10.1 Upper atmospheric discharges to the ionosphere	161
10.1.1 Space charge and electric field in a ground-cloud-ionosphere system	162
10.1.2 Electric cusp for a double-dipole cloud	164
10.1.3 Cloud-to-ionosphere discharges by electric reconnection	164
10.1.4 Lightning-to-aurora transition in cloud-to-ionosphere discharges	166
10.2 Nebular lightning and Chondrules formation	167
10.3 Ball lightning	168
10.4 Atmospheric, ionospheric, and magnetospheric effects associated with earthquakes	169
10.5 Interplanetary dust and planetary rings	171
10.5.1 Saturn's ring system	172
10.5.2 Role of electromagnetic processes in the formation of Saturn's ring system	175
10.5.3 Spokes and discontinuities in Saturn's B ring	181
10.5.4 Jupiter's rings	183

10.5.5 Quasi-periodic high-speed dust streams in Jupiter's magnetosphere	184
10.5.6 Cometary dusts	185
10.6 Planetary lightning and Saturn electrostatic discharges (SED)	187
10.6.1 Saturn electrostatic discharges (SED)	188
10.6.2 Jupiter's lightning	191
10.6.3 Venus' lightning or Venus plasma noise?	192
<i>References</i>	193
Index	199