Contents

Preface v

1 Mechanisma of Transverse Conductivity and Generation of Self-Consistent Electric Fields in Strongly Ionized Magnetized Plasma
V. Rozhansky 1
1.1 Introduction 1
1.2 Conductivity Tensor in Partially Ionized Plasma 4
1.3 Main Mechanisms of Perpendicular Conductivity in Fully Ionized Plasma: Currents Caused by Viscosity, Inertia, Collisions with Neutrals, and ∇B, and Mass-Loading Currents 6
1.3.1 Inertia Currents 6
1.3.2 Currents Caused by Ion–Neutral Collisions 7
1.3.3 Diamagnetic Currents 8
1.3.4 Viscosity-Driven Currents 8
1.3.5 Mass-Loading Current 10
1.4 Inertial (Polarization) and ∇B Currents. Acceleration of Plasma Clouds in an Inhomogeneous Magnetic Field 11
1.5 Alfven Conductivity 13
1.6 Perpendicular Viscosity, Radial Current, and Radial Electric Field in an Infinite Cylinder 15
1.7 Current Systems in Front of a Biased Electrode (Flush-Mounted Probe) and Spot of Emission 16
1.7.1 Viscosity-Driven Perpendicular Currents 18
1.7.2 Currents Driven by Ion–Neutral Collisions 22
1.7.3 Inertia Currents 23
1.7.4 General Situation 24
1.7.5 Spot of Emission 25
1.8 Currents in the Vicinity of a Biased Electrode That is Smaller Than the Ion Gyroradius 26
1.9 Neoclassical Perpendicular Conductivity in a Tokamak 30
1.9.1 Steady State Current 30
1.9.2 Time-Dependent Current 37
1.10 Transverse Conductivity in a Reversed Field Pinch 38
1.11 Modeling of Electric Field and Currents in the Tokamak Edge Plasma . . . 39

1.12 Mechanisms of Anomalous Perpendicular Viscosity and Viscosity-Driven Currents 41
1.13 Transverse Conductivity in a Stochastic Magnetic Field 43
1.13.1 Nonstochastic Magnetic Field 44
1.13.2 Stochastic Magnetic Field 45
1.14 Electric Fields Generated in the Shielding Layer between Hot Plasma and a Solid State 46
References 50

2 Correlations and Anomalous Transport Models
O.G. Bakunin 53
2.1 Introduction 53
2.2 Turbulent Diffusion and Transport 56
2.2.1 The Correlation Function and the Taylor Diffusivity 57
2.2.2 The Richardson Law 59
2.2.3 The Davydov Model of Turbulent Diffusion 60
2.2.4 The Batchelor Approximation for the Diffusion Coefficient 62
2.3 Nonlocal Effects and Diffusion Equations 63
2.3.1 The Functional Equation for Random Walks 64
2.3.2 Nonlocality and the Levy Distribution 65
2.3.3 The Monin Fractional Differential Equation 67
2.4 The Corrsin Conjecture 69
2.4.1 The Corrsin Independence Hypothesis 69
2.4.2 The Simplified Corrsin Conjecture 70
2.4.3 The Correlation Function and Scalings 71
2.5 Effects of Seed Diffusivity 72
2.5.1 Seed Diffusivity and Correlations 73
2.5.2 “Returns” and Correlations 74
2.5.3 The Stochastic Magnetic Field and Scalings 75
2.5.4 The Howells Result 77
2.6 The Diffusive Tracer Equation and Averaging 79
2.6.1 The Taylor Shear Flow Model 79
2.6.2 Generalization of the Taylor Model 82
2.6.3 The Zeldovich Flow and the Kubo Number 83
2.6.4 Advection and Zeldovich Scaling 85
2.7 The System of Random Shear Flows 86
2.7.1 The Dreizin–Dykhne Superdiffusion Regime 87
2.7.2 The Matheron–de Marsily Model 88
2.7.3 The “Manhattan Grid” Flow and Transport 91
2.8 The Quasi-Linear Approximation 93
2.8.1 Quasi-Linear Equations 93
2.8.2 Short-Range and Long-Range Correlations 95
2.8.3 The Telegraph Equation 96
2.8.4 Magnetic Diffusivity and the Kubo Number 97
2.9 The Diffusive Renormalization 98

2.9.1 The Dupree Approximation 99
2.9.2 The Dupree Theory Revisited 102
2.9.3 The Taylor–McNamara Correlation Function 104
2.9.4 The Kadomtsev–Pogutse Renormalization and the Stochastic Magnetic Field 106
2.10 Anomalous Transport and Convective Cells 108
2.10.1 Bohm Scaling and Electric Field Fluctuations 108
2.10.2 The Bohm Regime and Correlations 110
2.10.3 Convective Cells and Transport 112
2.10.4 Complex Structures and Convective Transport 114
2.11 Stochastic Instability and Transport 114
2.11.1 Stochastic Instability and Correlations 115
2.11.2 The Rechester–Rosenbluth Model 116
2.11.3 Collisional Effects and the Stix Formula 119
2.11.4 The Quasi-Isotropic Stochastic Magnetic Field and Transport . . . 121
2.11.5 Quasi-Linear Scaling for the Stochastic Instability Increment 123
2.12 Fractal Conceptions and Turbulence 125
2.12.1 Fractality and Transport 125
2.12.2 The Richardson Law and Fractality 127
2.12.3 Intermittency and the Kolmogorov Law 129
2.13 Percolation and Scalings 130
2.13.1 Continuum Percolation and Transport 130
2.13.2 Renormalization and Percolation 132
2.13.3 Graded Percolation 134
2.14 Percolation and Turbulent Transport Scalings 135
2.14.1 Random Steady Flows and Seed Diffusivity 136
2.14.2 The Spatial Hierarchy of Scales and Stochastic Instability 137
2.14.3 Low Frequency Regimes 138
2.15 The Temporal Hierarchy of Scales and Correlations 140
2.15.1 The Spatial and Temporal Hierarchy of Scales 140
2.15.2 The Isichenko Intermediate Regime 142
2.15.3 Dissipation and Percolation Transport 143
2.16 The Stochastic Magnetic Field and Percolation Transport 146
2.16.1 The Stochastic Magnetic Field and Percolation Transport 146
2.16.2 Percolation and the Kadomtsev–Pogutse Scaling 148
2.16.3 Percolation Renormalization and the Stochastic Instability Increment 150
2.17 Percolation in Drift Flows 151
2.17.1 Graded Percolation and Drift Flows 151
2.17.2 Low Frequency Regimes and Drift Effects 153
2.17.3 Compressibility and Percolation 155
2.18 Multiscale Flows 156
2.18.1 The Nested Hierarchy of Scales and Drift Effects 157
2.18.2 The Brownian Landscape and Percolation 159
2.18.3 Correlations and Transport Scalings 161

2.18.4 The Diffusive Approximation and the Multiscale Model 163
2.18.5 Stochastic Instability and Time Scales 165
2.18.6 Isotropic and Anisotropic Turbulent Energy Spectra 166
2.18.7 The Multiscale Model of Transport in a Tangled Magnetic Field . 168
2.19 Subdiffusion and Traps 169
2.19.1 The Balagurov and Vaks Model of Diffusion with Traps 170
2.19.2 Subdiffusion and Fractality 171
2.19.3 Comb Structures and Transport 172
2.20 Continuous Time Random Walks 173
2.20.1 The Montroll and Weiss Approach and Memory Effects 174
2.20.2 Fractional Differential Equations 176
2.20.3 The Taylor Definition and Memory Effects 177
2.21 Fractional Differential Equations and Scalings 180
2.21.1 The Klafter, Blumen, and Shlesinger Approximation 180
2.21.2 The Stochastic Magnetic Field and Balescu Approach 181
2.21.3 Longitudinal Correlations and the Diffusive Approximation 183
2.21.4 Vortex Structures and Trapping 185
2.21.5 Correlations and Trapping 187
2.22 Correlation and Phase-Space 189
2.22.1 The Corrsin Conjecture and Phase-Space 189
2.22.2 The Hamiltonian Nature of the Universal Hurst Exponent 191
2.22.3 The One-Flight Model and Transport 193
2.22.4 Correlations and Nonlocal Velocity Distribution 195
2.22.5 The Arrhenius Law and Phase-Space Distribution 197
2.23 Conclusion 198
Acknowledgements 198
References 198