

Contents

Preface	v
Introduction	333
Chapter 8. Toroidal magnetic confinement	337
8.1. Magnetic surfaces	337
8.2. Magnetohydrodynamic equilibrium. Toroidal coordinate systems	341
8.3. Surface quantities	343
8.4. Natural coordinate systems	346
8.5. Magnetic differential equations	352
8.6. Surface averages	357
8.7. The Clebsch representation	359
8.8. Axisymmetric systems	363
8.9. The standard model	373
References	378
Chapter 9. The motion of charged particles in toroidal magnetic fields	379
9.1. Introduction. Qualitative description of the motion	379
9.2. Exact equations of the charged particle motion in toroidal geometry	383
9.3. Equations of the guiding centre motion in toroidal geometry	391
9.4. The toroidal invariant of the motion	395
9.5. Topological classification of the guiding centre orbits	400
9.6. Shape of the guiding centre orbits	404
9.7. Solution of the equations of motion	411
9.8. Effects of electric drift and of non-axisymmetry	416
References	421
Chapter 10. Kinetic equation and local equilibrium of a magnetically confined plasma ..	423
10.1. Characteristic parameters	423
10.2. Kinetic equation and natural guiding centre variables	426
10.3. The multiple time-scale perturbation expansion	430
10.4. The drift kinetic equation	432
10.5. The local equilibrium state for a magnetically confined plasma	437
10.6. Ordering of the hydrodynamical quantities in a toroidally confined plasma ..	441
References	445
Chapter 11. Approximation methods for the kinetic equation	447
11.1. Test-particle collisions and field particle collisions	447
11.2. Expansion of the linearized collision term	452

11.3. Properties of the basis functions	459
11.4. The approximate collision operator	464
11.5. Explicit form of the drift kinetic equation	468
Appendix 11A.1. Calculation of the like-particle collision frequencies	471
References	474
 Chapter 12. Particle and energy fluxes in magnetically confined plasmas	475
12.1. Short and long mean free path regimes	475
12.2. The Hermitian moment expansion	479
12.3. The Chew–Goldberger–Low (CGL) pressure tensor	481
12.4. The vector moment equations	486
12.5. The average parallel fluxes	491
12.6. The quasi-transport equations	495
12.7. The perpendicular fluxes	498
12.8. The zero-divergence constraint. The “poloidal fluxes”	501
12.9. Decomposition of the average radial fluxes	509
12.10. The average parallel electric current	516
12.11. Microscopic expression of the fluxes	518
Appendix 12A.1. Proof of relation (9.3)	521
References	522
 Chapter 13. The classical fluxes and the Pfirsch–Schlüter effect	523
13.1. The electric drift fluxes and the modified drift fluxes	523
13.2. The classical fluxes	526
13.3. The Pfirsch–Schlüter fluxes	532
13.4. Classical and Pfirsch–Schlüter transport	539
Appendix 13A.1. Alternative derivation of the Pfirsch–Schlüter fluxes	545
References	549
 Chapter 14. Solution of the drift-kinetic equation in the long mean free path regime	551
14.1. Expansion of the distribution function according to the collision frequency	551
14.2. Integration of the zeroth-order drift kinetic equation	554
14.3. The integrability conditions of the first-order drift kinetic equation	556
14.4. Solution of the integrability constraints	562
14.5. The NGC variables: x, λ, ϕ	565
14.6. Expansion of the zeroth-order distribution function	570
14.7. Relation between the zeroth-order distribution function and the macroscopic fluxes to order ϵ	574
14.8. The function f_p and the neoclassical factor φ	576
14.9. Strategy for the solution of the first-order drift kinetic equation	581
14.10. Three properties of the drift kinetic collision operator	582
14.11. Relation between generalized stresses and poloidal fluxes	585
14.12. The pseudo-viscosity coefficients	590
Appendix 14A.1. Proof of the Alfvén formula (2.9)	592
Appendix 14A.2. Integrals involving the Chandrasekhar function $\mathcal{H}(x)$	595
References	598

 Chapter 15. The banana transport equations	599
15.1. Strategy of the derivation of the banana transport equations	599
15.2. Derivation of the banana transport coefficients	601
15.3. The transport equations in the long mean free path regime	606
15.4. Numerical values of the transport coefficients. Limiting values. Convergence of the approximation procedure	615
15.5. Discussion of the banana transport coefficients	623
References	639
 Chapter 16. The intermediate mean free path regime. Interpolation formulae for the transport coefficients	641
16.1. Introduction	641
16.2. The NGC variables x, ξ, ϕ	642
16.3. The plateau regime	648
16.4. The pseudo-viscosity coefficients in the plateau regime	652
16.5. The plateau transport equations	656
16.6. Interpolation formulae for the diffusion coefficient	664
16.7. Approximate transport equations for the entire collision frequency range	668
16.8. Miscellaneous additional topics	679
Appendix 16A.1. Some useful integrals	686
References	687
 Chapter 17. Entropy production and transport in magnetically confined plasmas	689
17.1. Introduction	689
17.2. The unaveraged entropy production	691
17.3. Entropy production and quadratic forms	696
17.4. Decomposition of the parallel fluxes	701
17.5. The surface-averaged entropy production	706
17.6. The Pfirsch–Schlüter average entropy production	712
17.7. The average banana entropy production	716
17.8. Transport coefficients and entropic coefficients	721
17.9. Conclusions and comparison with other works	732
Appendix 17A.1. Some properties of the collision matrix and of the parallel quasi-transport matrix	734
Appendix 17A.2. Positivity of the entropic coefficient p_{EE}	738
References	739
 Chapter 18. Toroidal plasmadynamics	741
18.1. The problem of one-dimensional toroidal plasmadynamics	741
18.2. Toroidal plasmadynamics: fluid-dynamical aspects	743
18.3. Toroidal plasmadynamics: electrodynamical aspects	753
18.4. Discussion of the toroidal plasmadynamical equations	763
18.5. The neoclassical confinement times	766
References	771

Chapter 19. The limitations of the classical and neoclassical transport theories. The runaway effect	773
19.1. The conceptual framework of classical and neoclassical transport theories	773
19.2. The runaway effect	775
19.3. Microscopic aspects of the runaway effect	781
19.4. The emergence of anomalous transport	786
References	788
General appendix 2. Curvilinear coordinate systems	789
G2.1. Non-orthogonal coordinate systems	789
G2.2. Orthogonal coordinate systems	796
G2.3. Concentric circular toroidal coordinates	800
References	803
Author index	xvii
Subject index	xxiii
Index of notations	xxix