## CONTENTS

1	Introduction			
	1.1	Computer and Computer Simulation	1	
	1.2	Dynamical Systems of Many Degrees of Freedom	7	
	1.3	Particle Simulation and Finite-Size Particles	13	
	1.4	Limitations on Simulation—Future Directions	21	
	1.5	Hierarchical Nature and Simulation Methods	28	
2	Finite Size Particle Method			
	2.1	Gridless Theory of a Finite-Size Particle System	38	
	2.2	Dispersion Relation	41	
	2.3	Collisional Effects Due to Finite-Size Particles	43	
	2.4	Fluctuations	46	
3	Tin	Time Integration 5		
-	3.1	Euler's First-Order Scheme	53	
	3.2	Leapfrog Scheme	54	
	3.3	Biasing Scheme	57	
	3.4	Runge-Kutta Method	64	
	3.5	Diffusion Equation	68	
4	Grid Method			
	4.1	Grid Method and the Dipole Expansion	74	
	4.2	Area Weighting Scheme	78	
	4.3	Examples of Electrostatic Codes	81	
	4.4	Spatially Periodic Systems	83	
	4.5	Consequences of the Grid for the Vlasov Theory of Plasmas	88	
	4.6	Smoother Grid Assignment	95	

## XX CONTENTS

5	Electromagnetic Model		105
Ŭ.	5.1	Electromagnetic Particle Simulation Code	105
	5.2	Analogy Between Electrodynamics and General Relativity	108
	5.3	Absorbing Boundary for the Electromagnetic Model	109
	5.4	Magnetoinductive Particle Model	113
	5.5	Method of Relaxation	119
	5.6	Hyperbolic, Parabolic, and Elliptic Equations	121
	5.7	Classification of Second-Order P.D.E.	126
6	Magnetohydrodynamic Model of Plasmas		
•	6.1	Difficulty with the Advective Term	142
	62	Lax Scheme	143
	6.3	Lax-Wendroff Scheme	145
	64	Leapfrog Scheme	148
	6.5	Flux-Corrected Transport Method	149
	6.6	Magnetohydrodynamic Particle Model	152
	67	Reduced Magnetohydrodynamic Equations	161
	6.8	Spectral Method	165
	6.9	Semi-Implicit Method	173
	6 10	Unwind Differencing	177
	6.11	Discussion of Various Methods	176
-		1' Center Method	189
4	Gui	Ding-Center Method	190
	7.1	EXBUILT Gilling Conton Model	191
	7.2	Guiding-Center Model	194
	7.3	Numerical Methods for Guiding-Center Plasmas	200
	7.4	Polarization Dritt	202
	7.5	Geostrophic Flows	205
	7.6	Finite Larmor Radius Enects	207
	7.7 7.8	Guiding-Center Magnetoinductive Model	215
			227
8	Hybrid Models of Plasmas		227
	8.1	Quasineutral Electrostatic Model	229
	8.2	Quasineutral Electromagnetic Model	233
	8.3	Particle Electron-Fluid Ion Model	200
9	Implicit Particle Codes		238
	9,1	First Order Accurate Methods	240
	9.2	Implicit Time Filtering	241
	9.3	Decentered Lorentz Pusher	245
	9.4	Techniques for Direct Implicit Advancing	246

		CONTENTS	xxi
	9.5	Direct Implicit Electromagnetic Algorithm	248
	9.6	Gyrokinetic Model (Revisited)	254
	9.7	Large Time Scale-Large Spatial Scale Simulation	258
10	Geometry		
	10.1	MHD Particle Code	270
	10.2	Toroidal Corrections	281
	10.3	Electrostatic Particle Code	283
	10.4	Method of Flux Coordinates	290
11	Info	rmation and Computation	298
	11.1	The Future of Computers	298
	11.2	Computation on a Cellular Automaton	303
	11.3	Information Processing	308
	11.4	Information and Entropy	314
	11.5	Correlation Analysis and Maximum Entropy	322
12	Interaction Between Radiation and a Plasma		
	12.1	Radiation from Particle Beams	334
	12.2	Laser Plasma Accelerators	337
	12.3	Ion Cyclotron Resonance Heating of a Plasma	356
13	Drift Waves and Plasma Turbulence		
	13.1	Drift Wave Instabilities	369
	13.2	Shear Flow Instability	385
	13.3	Heat Convection Instability	390
14	Magnetic Reconnection		405
	14.1	Collisionless Tearing Instabilities	409
	14.2	Linear Theory of Driven Reconnection	415
	14.3	Fast Reconnection	419
	14.4	Coalescence Instability	423
	14.5	Theory of Explosive Coalescence and Comparison with Simulation	431
	14.6	Current Loop Coalescence Model of Solar Flares	442
	14.7	Reconnection-Driven Oscillations in Dwarf Nova Disks	448
15	Tra	nsport	457
	15.1	Monte-Carlo Method	458

459

15.2 Fokker-Planck Model

## xxII CONTENTS

15.3 Particle Transport for Energetic Particles 15.4 Mapping Methods	463 469
Epilogue: Numerical Laboratory	486
Subject Index	488
Author Index	494
Credits	502