

# Contents

## Preface

v

<b>I Introduction</b>	<b>1</b>
<b>1 Computer Experiments of Space Plasmas</b>	<b>3</b>
1.1 Role of the Computer Experiment . . . . .	3
1.2 History of the Computer Experiment . . . . .	5
1.3 Theory, Space- and Computer-Experiments . . . . .	7
1.3.1 Nonlinear Plasma Effect caused by Intense Monochromatic Microwave . . . . .	7
1.3.2 Theory of Nonlinear Excitation of Plasma Waves by Intense Monochromatic Electromagnetic Wave . . . . .	8
1.3.3 MINIX Rocket Experiment . . . . .	9
1.3.4 Computer Experiment . . . . .	11
1.4 Conclusion . . . . .	17
<b>II Simulation Techniques</b>	<b>19</b>
<b>2 KEMPO1</b>	<b>21</b>
2.1 Introduction . . . . .	21
2.1.1 Basic equations . . . . .	22
2.1.2 Grid assignment . . . . .	23
2.1.3 Time step chart . . . . .	23
2.1.4 Courant condition . . . . .	24
2.1.5 Debye length . . . . .	25
2.2 MAIN . . . . .	26
2.2.1 Electromagnetic simulation . . . . .	26
2.2.2 Electrostatic simulation . . . . .	29
2.3 INPUT . . . . .	30
2.4 RENORM . . . . .	34
2.5 INITAL . . . . .	34
2.6 POSITN . . . . .	37

2.7	VELCTY	37
2.8	EFIELD	41
2.9	BFIELD	42
2.10	CHARGE	42
2.11	ECRRCT	44
2.12	CURRNT	45
2.13	CURNTV	51
2.14	Diagnostics of KEMPO1	53
2.14.1	FLDPLT	54
2.14.2	KSPPLT	54
2.14.3	PHSPLT	54
2.14.4	VDSPLT	58
2.14.5	SPECTR	58
2.14.6	ENERGY	60
2.15	Exercises of KEMPO1	60
2.15.1	Single particle motion	60
2.15.2	Thermal fluctuations	61
2.15.3	Two stream instability	61
2.15.4	Buneman instability	62
2.15.5	Non-cancellation of the uniform current	62
2.15.6	Whistler mode beam instability	62
2.15.7	Weibel instability	62
2.15.8	Violation of Courant condition	62
2.15.9	Numerical heating of a plasma	62
2.15.10	Electrostatic simulation	62
2.15.11	Vectorization of CHARGE	63
2.16	LIBKEMPO1	63
2.17	Installation of KEMPO1	63
<b>3</b>	<b>TRISTAN</b>	<b>67</b>
3.1	Introduction	67
3.2	Field Update	68
3.3	Particle Update	69
3.4	Speed Limits	70
3.5	Interpolation	71
3.6	Charge Fluxes	72
3.7	Smoothing	72
3.8	Sorting and Localisation	74
3.9	Boundary Conditions: Particles	74
3.10	Boundary Conditions: Fields	75
3.11	Initialisation	80
3.12	Postprocessing	82

<b>4 MACRO-EM</b>	<b>85</b>
4.1 Introduction . . . . .	85
4.2 General Algorithm . . . . .	88
4.2.1 Field and particle equations . . . . .	88
4.2.2 Equations in the finite difference form . . . . .	89
4.2.3 Coupled field-particle equations . . . . .	90
4.2.4 Miscellaneous . . . . .	91
4.3 Alfvén-Ion-Cyclotron Instability . . . . .	92
4.4 Kinetic Alfvén Waves . . . . .	96
4.5 Conclusion . . . . .	99
<b>5 HYBRID CODES</b>	<b>103</b>
5.1 Basics . . . . .	104
5.1.1 Introduction . . . . .	104
5.1.2 Equations . . . . .	106
5.2 Simple One-Dimensional Hybrid Code . . . . .	107
5.2.1 Units and spatial grid . . . . .	108
5.2.2 Ion dynamics . . . . .	109
5.2.3 Electrons . . . . .	111
5.2.4 Electromagnetic fields . . . . .	113
5.2.5 Initialization . . . . .	117
5.2.6 Diagnostics . . . . .	118
5.3 Simple Applications . . . . .	119
5.3.1 Resonant electromagnetic ion/ion instability . . . . .	120
5.3.2 Numerical checks . . . . .	131
5.3.3 Nonresonant electromagnetic ion/ion instability . . . . .	137
5.3.4 Electromagnetic ion cyclotron beam anisotropy instability	139
5.3.5 Modifying the Code . . . . .	141
5.4 Discussion . . . . .	146
<b>6 TWO-DIMENSIONAL MHD CODE</b>	<b>161</b>
6.1 Introduction . . . . .	161
6.1.1 General remarks on tutorial course on MHD simulation	161
6.1.2 A survey of global MHD simulations . . . . .	162
6.2 Global MHD Model of Magnetosphere . . . . .	164
6.2.1 Basic equations . . . . .	164
6.2.2 Coordinate system and boundary conditions . . . . .	165
6.2.3 Initial conditions . . . . .	167
6.3 Description of 2-Dimensional MHD Code . . . . .	168
6.3.1 2-dimensional case of basic equations . . . . .	168
6.3.2 Coordinate system and boundary conditions . . . . .	170
6.3.3 Initial conditions . . . . .	172
6.3.4 Application of two-step Lax-Wendroff method . . . . .	172

6.4	Execution of 2-Dimensional MHD Code . . . . .	177
6.4.1	Set up of numerical parameters . . . . .	177
6.4.2	Examples of execution . . . . .	178
6.4.3	Graphics output . . . . .	178
6.5	MHD Simulation of Earth's Magnetosphere . . . . .	183
6.5.1	2-dimensional simulation results . . . . .	183
6.5.2	3-dimensional simulation results . . . . .	185
6.5.3	High resolution MHD simulation . . . . .	185
6.6	Concluding Remarks . . . . .	191
<b>7</b>	<b>HIGH-PRECISION MHD SIMULATION</b>	<b>209</b>
7.1	Introduction . . . . .	209
7.2	2-Step Lax-Wendroff Scheme . . . . .	210
7.3	High Precision Scheme . . . . .	211
7.4	Other Schemes . . . . .	214
<b>8</b>	<b>TUTORIAL FOR UNIX OPERATIONS</b>	<b>217</b>
8.1	Basic Operations in UNIX Operating System . . . . .	217
8.1.1	Computer environments in ISSS-4 . . . . .	217
8.1.2	How to login/logout . . . . .	218
8.1.3	Operations for directories and listing the contents . . . . .	219
8.1.4	Operations for regular files . . . . .	221
8.2	Screen Editor (vi) Tutorial . . . . .	221
8.2.1	Basic commands . . . . .	222
8.2.2	Positioning the cursor in undisplayed text . . . . .	223
8.2.3	Modifying text . . . . .	224
8.2.4	Yanking and putting text . . . . .	224
8.2.5	Other commands . . . . .	225
8.3	How to Compile Fortran Programs . . . . .	225
8.4	What Are <code>make</code> and <code>Makefile</code> . . . . .	226
8.5	What IS X Window System . . . . .	227
8.6	How to Make Your Own Graphic Library . . . . .	229
<b>III</b>	<b>Simulation Software</b>	<b>235</b>
<b>9</b>	<b>KEMPO1</b>	<b>237</b>
<b>10</b>	<b>TRISTAN</b>	<b>305</b>
<b>11</b>	<b>MACROEM</b>	<b>323</b>
<b>12</b>	<b>HYBRID1</b>	<b>363</b>

<i>CONTENTS</i>	xi
<b>13 MHD2</b>	<b>411</b>
<b>14 WAVE</b>	<b>469</b>
<b>Author List</b>	<b>483</b>
<b>Index</b>	<b>485</b>