

CONTENTS

<i>Preface</i>	xi
1 Introduction	1
1.1 Brief description of spheromaks	1
1.2 History and time-line	6
2 Basic Concepts	17
2.1 Vacuum magnetic fields	17
2.2 Poloidal and toroidal fields	18
2.3 Magnetic stress tensor	20
2.4 Beta	24
2.5 Magnetic flux and symmetry	24
2.6 Poloidal flux	24
2.7 Poloidal flux and particle confinement	25
2.8 Relation between field, field lines, and flux	26
2.9 Safety factor	28
2.10 The plasma as a magnetic flux conserver	32
2.11 The condition for frozen-in flux	33
2.12 Tendency of the plasma to maximize its inductance	35
2.13 Cowling's theorem	35
3 Magnetic Helicity	37
3.1 The issue of analyticity in Gauss's and Stokes's theorems	37
3.2 Definition of magnetic helicity	39
3.3 Helicity, safety factor, and twist of an isolated flux tube	42
3.4 Gauge invariance	45
3.5 Relative helicity	45
3.6 Simply connected volumes v. doubly connected volumes	49
3.7 Helicity conservation equation	50
3.8 Single species helicity	58
3.9 Magnetic reconnection	60
3.10 Geometric interpretation of magnetic helicity	61
3.11 Magnetic reconnection and helicity conservation	63
3.12 Reconnection and dissipation	66
4 Relaxation of an Isolated Configuration to the Taylor State	71
4.1 Introduction	71

4.2	Helicity decay rate v. magnetic energy decay rate	72
4.3	Derivation of the isolated Taylor state	73
4.4	Relationship between helicity, energy, eigenvalue	75
4.5	Cylindrical force-free states	77
4.6	Comparison of minimum energy states in a long cylinder	79
4.7	Spheromaks in spherical geometry	80
5	Relaxation in Driven Configurations	87
5.1	Taylor relaxation in systems with open field lines	87
5.2	Helicity injection	91
5.3	Impedance of the driven force-free configuration	92
6	The MHD Energy Principle, Helicity, and Taylor States	95
6.1	Derivation of the MHD Energy Principle	95
6.2	Relationship of the energy principle to Taylor states	101
6.3	Beta limit	103
7	Survey of Spheromak Formation Schemes	109
7.1	Magnetized coaxial gun	110
7.2	Non-axisymmetric gun method	117
7.3	The inductive method	117
7.4	Z-Theta pinch method	120
8	Classification of Regimes: an Imperfect Analogy to Thermodynamics	123
8.1	Analogy to thermodynamics	123
8.2	Classification of thermodynamic problems	123
8.3	Analogy between lambda and temperature	126
8.4	Strong and weak coupling	128
8.5	Overview of next five chapters	128
9	Analysis of Isolated Cylindrical Spheromaks	129
9.1	Flux, current, magnetic field, helicity and energy	129
9.2	Experimental measurements	135
9.3	Safety factor	136
10	The Role of the Wall	143
10.1	Helicity insulation	143
10.2	Equilibrium	143
10.3	Tilt stability	146

11	Analysis of Driven Spheromaks: Strong Coupling	155
11.1	Force-free equilibria with open field lines	156
11.2	Flux surfaces	162
11.3	Safety factor variation with lambda	167
11.4	Flux amplification	170
11.5	Relative helicity	171
11.6	Relative energy	174
11.7	Gun efficiency	175
11.8	Gun impedance and load line	177
12	Helicity Flow and Dynamos	183
12.1	Downhill flow of helicity	183
12.2	Dynamos and relaxation mechanisms	185
12.3	Observations of dynamo behavior	189
12.4	Deviation from the Taylor state	196
12.5	MHD dynamo, helicity flux, and lambda gradient	199
13	Confinement and Transport in Spheromaks	207
13.1	Overview	207
13.2	Confinement times	209
13.3	Survey of transport mechanisms	209
13.4	Experiments on transport in spheromaks	218
13.5	Anomalous ion heating	222
14	Some Important Practical Issues	227
14.1	Breakdown and Paschen curves	227
14.2	Gas puff valves	232
14.3	Wall desorption and contamination	234
14.4	Impurity line radiation	236
14.5	Refractory electrode materials	239
14.6	Skin effect and the wall as a flux conserver	239
14.7	Inductance budget	240
14.8	Mechanical forces	241
14.9	Noise radiation from pulsed power supplies	241
14.10	Ground loops	242
15	Basic Diagnostics for Spheromaks	243
15.1	Magnetic field and electric current measurement	243
15.2	Equilibrium reconstruction using measurements at the wall	248
15.3	Voltage measurements	248

15.4	Density measurement	249
15.5	Ion temperature measurement	255
15.6	Electron temperature measurement	257
15.7	Impurity radiation measurements	260
16	Applications of Spheromaks	263
16.1	The spheromak as a fusion reactor	263
16.2	Accelerated spheromaks	269
16.3	Tokamak Fuel injection	274
16.4	Helicity injection current drive in tokamaks	275
16.5	Colliding spheromaks to investigate magnetic reconnection	277
16.6	Proposed additional spheromak applications	281
17	Solar and Space Phenomena Related to Spheromaks	283
17.1	Sun-Earth connection viewed as helicity flux/relaxation	291
17.2	A spheromak-like laboratory model of solar prominences	293
17.3	S-shapes	297
17.4	Flux tube bifurcation and breakup	298
17.5	Comparison of magnetic field, field lines, flux tubes	299
17.6	Relaxation and line tying	300
17.7	Prominence simulation experiment	300
	<i>References</i>	303
	<i>Appendix A: Vector Identities and Operators</i>	315
	<i>Appendix B: Bessel Orthogonality Relations</i>	317
	<i>Appendix C: Capacitor Banks</i>	321
	<i>Appendix D: Selected Formulae</i>	325
	<i>Index</i>	333