

# Contents

PREFACE .....	ix
1. INTRODUCTION .....	1
1.1 Taylor's Theory of Plasma Relaxation .....	2
1.2 The Underlying Physics of Plasma Relaxation.....	6
1.3 Toroidal Systems and the RFP .....	9
1.4 Overview of the Remainder of the Book.....	12
2. THE RESISTIVE MAGNETOHYDRODYNAMIC MODEL.....	15
2.1 Resistive Magnetohydrodynamics.....	15
<i>The Physical Model</i> .....	15
<i>The Evolution of the Fluid</i> .....	17
<i>The Evolution of the Electromagnetic Fields</i> .....	21
<i>Characteristic Oscillations; Normal Modes</i> .....	22
<i>Dimensionless Variables; the Lundquist Number</i> .....	25
2.2 MHD Stability .....	26
<i>Linear Stability of Normal Modes</i> .....	26
<i>Magnetic Shear and Singular Surfaces</i> .....	28
<i>Toroidal Pinch Configurations</i> .....	29
<i>Resistive Instabilities</i> .....	31
<i>Nonlinear Effects</i> .....	37
2.3 Stability Properties of the RFP.....	39
2.4 The Force Free MHD Model.....	42
2.5 The Role of Numerical Simulation .....	43
3. TAYLOR'S THEORY OF PLASMA RELAXATION .....	47
3.1 The Constraints of Ideal MHD.....	48
<i>The Woltjer Constraints</i> .....	48
<i>The Topological Properties of the Woltjer Constraints</i> .....	50
3.2 Energy Minimization with the Constraints of Ideal MHD.....	51

3.3	The Effect of Plasma Resistivity.....	53			
	<i>Taylor's Conjecture</i> .....	53			
3.4	Energy Minimization with the Global Helicity Constraint.....	54			
	<i>Validity of Taylor's Conjecture</i> .....	55			
	<i>Properly Defined Helicity</i> .....	57			
	<i>The Role of Plasma Pressure in Taylor's Theory</i> .....	58			
3.5	Predictions of the Theory.....	58			
	<i>The Reversed-Field Pinch</i> .....	58			
	<i>Summary of RFP Predictions</i> .....	61			
	<i>The Multipinch Experiment</i> .....	62			
3.6	Discussion.....	63			
4.	PHENOMENOLOGY OF RELAXATION IN THE REVERSED-FIELD PINCH.....	67			
4.1	Mean Field Profiles.....	68			
4.2	The Stability of Relaxed States.....	74			
4.3	Resistive Diffusion.....	82			
4.4	The Phenomenological Cyclical Model.....	87			
4.5	Experimental Observations of Relaxation Phenomena in the RFP.....	88			
5.	THE DYNAMICS OF PLASMA RELAXATION.....	95			
5.1	Classical Dynamo Theory.....	96			
	<i>Kinematic Dynamos</i> .....	97			
	<i>Cowling's Theorem</i> .....	99			
	<i>The Turbulent Dynamo</i> .....	101			
	<i>Relevance to the RFP Dynamo</i> .....	102			
5.2	The Basic Relaxation Mechanism.....	104			
	<i>The Original Work of Sykes and Wesson</i> .....	104			
	<i>Spontaneous and Driven Reconnection in the RFP</i> .....	106			
	<i>Fluctuations and Ohm's Law</i> .....	110			
	<i>Evidence of Taylor Relaxation</i> .....	111			
	<i>The Helical Ohmic State</i> .....	113			
5.3	Effects of Nonlinear Mode Coupling.....	115			
	<i>MHD Fluctuations</i> .....	115			
	<i>Nonlinear Mode Coupling</i> .....	118			
5.4	Summary.....	126			
6.	PRACTICAL ISSUES RELATED TO RELAXATION.....	129			
6.1	Anomalous Loop Voltage.....	130			
	<i>Perfectly Conducting Outer Boundary</i> .....	130			
	<i>Operation with Resistive Walls and Limiters</i> .....	130			
	<i>Helicity Balance</i> .....	138			
6.2	Taming the Dynamo; An Application of the Theory.....	139			
7.	RELAXATION AND THERMAL TRANSPORT.....	143			
7.1	A Model for Sawtooth Oscillations in the RFP.....	144			
	<i>Experimental Observations</i> .....	144			
	<i>Theoretical Interpretation of the Sawtooth Crash</i> .....	145			
7.2	Thermal Transport During Sawtooth Oscillations.....	148			
	<i>Energy Confinement Time</i> .....	148			
	<i>Modifications to the Resistive MHD Model</i> .....	149			
	<i>Simulation of Sawtooth Oscillations</i> .....	150			
7.3	Summary.....	154			
8.	DYNAMICAL RELAXATION IN THE SOLAR CORONA.....	155			
8.1	Overview of Coronal Dynamics.....	155			
8.2	Magnetic Arcade Evolution.....	157			
8.3	Coronal Current Filaments.....	163			
8.4	An Analogy Between the Solar Corona and the RFP.....	170			
9.	SUMMARY.....	171			
9.1	Relaxation in the Reversed-field Pinch.....	172			
9.2	Relaxation and Transport.....	174			
9.3	Relaxation in the Solar Corona.....	175			

viii Contents

9.4 Critique.....	175
<i>To what extent can the numerical simulations be believed? .....</i>	176
<i>What about analytic theory? .....</i>	176
<i>What is the role of turbulence? .....</i>	176
<i>Are pressure driven modes important? .....</i>	177
<i>Are there non-MHD effects? .....</i>	177
<i>What is the future of relaxation studies? .....</i>	177
REFERENCES .....	179
INDEX .....	185