



## Contents

### Preface IX

<b>1</b>	<b>Differential Rotation of Stars</b>	<b>1</b>
1.1	Solar Observations	2
1.1.1	The Rotation Law	2
1.1.2	Torsional Oscillations	5
1.1.3	Meridional Flow	6
1.2	Stellar Observations	9
1.2.1	Rotational Evolution	9
1.2.2	Differential Rotation	11
1.3	The Reynolds Stress	13
1.3.1	The $\Lambda$ Effect	14
1.3.1.1	Numerical Simulations	15
1.3.1.2	Quasi-linear Theory of the $\Lambda$ Effect	19
1.3.2	Eddy Viscosities	22
1.4	The Meridional Flow	24
1.4.1	Origin of the Meridional Flow	26
1.4.2	The Differential Temperature	28
1.4.3	Advection-Dominated Solar Dynamo	32
1.5	The Sun	35
1.5.1	Sun without $\Lambda$ Effect	38
1.5.2	Sun without Baroclinic Flow	39
1.5.3	Global Simulations	40
1.6	Individual Stars	42
1.6.1	Two Most Stars	44
1.6.2	Young Stars	46
1.7	Dwarfs & Giants	50
1.7.1	M Dwarfs	50
1.7.2	F Stars	51
1.7.3	Giants	55
1.8	Differential Rotation along the Main Sequence	58

<b>2</b>	<b>Radiation Zones: Magnetic Stability and Rotation</b>	63
2.1	The Watson Problem	65
2.1.1	The Stability Equations	65
2.1.2	2D Approximation	67
2.1.3	Stability Maps	69
2.2	The Magnetic Tachocline	72
2.2.1	A Planar Model	72
2.2.2	Magnetic Field Confinement by Meridional Flow	75
2.2.3	Tachocline Model in Spherical Geometry	79
2.3	Stability of Toroidal Fields	82
2.3.1	Equations	82
2.3.2	Nonexistence of 2D Magnetic Instabilities	85
2.3.3	No Diffusion	86
2.3.4	Growth Rates, Drift Rates and Radial Mixing	88
2.4	Stability of Thin Toroidal Field Belts	91
2.4.1	Rigid Rotation	92
2.4.2	Differential Rotation	93
2.4.3	High Fourier Modes	94
2.5	Helicity and Dynamo Action	94
2.5.1	Helicity and Alpha Effect	95
2.5.2	Dynamo Action	100
2.6	Ap Star Magnetism	103
2.7	The Shear-Hall Instability (SHI)	109
<b>3</b>	<b>Quasi-linear Theory of Driven Turbulence</b>	115
3.1	The Turbulence Pressure	116
3.2	The $\eta$ -Tensor	124
3.2.1	Rotating Turbulence	124
3.2.2	Nonrotating Turbulence but Helical Background Fields	128
3.3	Kinetic Helicity and DIV-CURL Correlation	131
3.4	Cross-Helicity	134
3.4.1	Theory	135
3.4.2	Simulations and Observations	136
3.5	Shear Flow Electrodynamics	138
3.5.1	Hydrodynamic Stability of Shear Flow	138
3.5.2	The Magnetic-Diffusivity Tensor	140
3.5.3	Dynamos without Stratification	141
3.6	The Alpha Effect	143
3.6.1	Helical-driven Turbulence	143
3.6.2	Shear Flow	145
3.6.3	Shear-Dynamos with Turbulence-Stratification	149
3.6.4	Alpha Effect by Density Stratification	150
3.7	The Current Helicity	153

<b>4</b>	<b>The Galactic Dynamo</b>	157
4.1	Magnetic Fields of Galaxies	157
4.2	Interstellar Turbulence	161
4.2.1	Hydrostatic Equilibrium and Interstellar Turbulence	162
4.2.2	Alpha Effect by Supernova Explosions	165
4.2.3	The Advection Problem	168
4.3	Dynamo Models	170
4.3.1	Linear Models	171
4.3.2	Nonlinear Dynamo Models	173
4.4	Magnetic Instabilities	175
4.4.1	The Seed Field Problem	175
4.4.2	Magnetorotational Instability	176
4.4.3	Taylor Instability	180
<b>5</b>	<b>The Magnetorotational Instability (MRI)</b>	185
5.1	Taylor–Couette Flows	185
5.2	The Stratrorotational Instability (SRI)	188
5.2.1	The Angular Momentum Transport	192
5.2.2	Electromotive Force by Magnetized SRI	195
5.3	The Standard Magnetorotational Instability (SMRI)	198
5.3.1	The Equations	200
5.3.1.1	The Rayleigh Limit	202
5.3.1.2	Pseudo-Kepler Rotation	203
5.3.2	Nonaxisymmetric Modes	204
5.3.3	Wave Numbers	206
5.3.4	Nonlinear Simulations	208
5.3.5	The Angular Momentum Transport	211
5.4	Diffusive Kepler Disks	214
5.5	MRI with Hall Effect	216
5.6	The Azimuthal MRI (AMRI)	218
5.6.1	The Equations	219
5.6.2	The Instability Map	223
5.6.3	Different Scalings with $P_m$	224
5.6.4	Nonlinear Results	224
5.6.5	The AMRI Experiment	228
5.7	Helical Magnetorotational Instability (HMRI)	231
5.7.1	From AMRI to HMRI	231
5.7.2	Nonaxisymmetric Modes for small $P_m$	236
5.7.3	Pseudo-Kepler Rotation	236
5.7.4	The Frequencies	237
5.8	Laboratory Experiment PROMISE	238
5.8.1	Experimental Results	240
5.8.2	Endplate Effects	242
5.8.3	PROMISE 2	244

<b>6</b>	<b>The Tayler Instability (TI)</b>	247
6.1	Stationary Fluids	249
6.2	Experiment GATE	254
6.3	Rotating Fluids	256
6.3.1	Rigid Rotation	257
6.3.2	Differential Rotation	258
6.3.3	Eddy Viscosity and Turbulent Diffusivity	262
6.3.3.1	Eddy Viscosity	262
6.3.3.2	Turbulent Diffusivity	263
6.3.3.3	Mixing of Chemicals	265
6.4	The Tayler Generator	267
6.5	Helical Background Fields and Alpha Effect	272
6.5.1	Helical Fields with Weak Axial Current	272
6.5.2	Uniform Electric Current	275
6.5.3	Alpha Effect	278
6.5.3.1	The Helicities	278
6.5.3.2	The Alpha Effect	280
6.6	TI with Hall Effect	282
<b>7</b>	<b>Magnetic Spherical Couette Flow</b>	287
7.1	Stewartson Layers	287
7.2	Shercliff Layers	289
7.3	Finite Re in an Axial Field	296
7.3.1	Numerics	296
7.3.2	The Maryland Experiment	302
7.3.3	The Princeton Experiment	305
7.4	The Grenoble DTS Experiment	307
7.5	Other Waves and Instabilities	313
7.5.1	Inertial Oscillations	313
7.5.2	Torsional Oscillations	314
7.5.3	Alfvén Waves	316
7.5.4	The Magnetostrophic MRI	317
7.6	Linear Combinations of Axial and Dipolar Fields	318
7.7	Dynamo Action	321
<b>References</b>		327
<b>Index</b>		341

