

# MAGNETOSPHERIC PHYSICS

Instructor: Antonius Otto

May 5, 2006

# Contents

<b>1</b>	<b>Introduction</b>	<b>5</b>
1.1	Preliminaries . . . . .	5
1.2	History of the Earth's magnetosphere . . . . .	6
1.3	Structure of the Magnetosphere . . . . .	10
1.4	Coordinate Systems . . . . .	13
1.4.1	Geographic Coordinates (GEO) . . . . .	13
1.4.2	Geocentric Equatorial Inertial (GEI) Coordinates: . . . . .	13
1.4.3	Geocentric Solar Ecliptic (GSE) . . . . .	14
1.4.4	Geomagnetic Coordinates (MAG) . . . . .	14
1.4.5	Geocentric Solar Magnetic (GSM) . . . . .	14
<b>2</b>	<b>Basic Plasma Properties</b>	<b>15</b>
2.1	First Principles . . . . .	15
2.1.1	Maxwell's Equations . . . . .	15
2.1.2	Lorentz Equations of Motion . . . . .	16
2.1.3	Plasma Properties and Parameters . . . . .	16
2.2	Kinetic Equations . . . . .	18
2.3	Derivation of the Fluid Plasma Equations . . . . .	20
2.3.1	Definitions . . . . .	20
2.3.2	Fluid Moments . . . . .	21
2.3.3	Typical Fluid Approximations . . . . .	23
2.4	Plasma (Two-) Fluid Equations . . . . .	25
2.5	Single Fluid or MHD Equations . . . . .	26
2.6	Properties of the Two-Fluid and MHD equations: . . . . .	28
2.7	Tables of Plasma Parameters . . . . .	30

<b>3</b>	<b>Electromagnetic Fields in Space</b>	<b>33</b>
3.1	Magnetic Fields . . . . .	35
3.1.1	Representation . . . . .	35
3.1.2	Dipole Magnetic Field . . . . .	36
3.1.3	Field Line Representation by the Vector potential . . . . .	38
3.1.4	Local Magnetic Field Properties . . . . .	39
3.1.5	Magnetic Fields and Electrical Current . . . . .	42
3.2	Electric Fields . . . . .	43
<b>4</b>	<b>Single Particle Dynamics</b>	<b>46</b>
4.1	Gyro Motion . . . . .	46
4.2	Particle Drifts . . . . .	47
4.2.1	Electric Force Drift . . . . .	47
4.2.2	Polarization Drift . . . . .	48
4.2.3	Magnetic Gradient Drift . . . . .	49
4.2.4	Magnetic Curvature Drift . . . . .	50
4.2.5	Summary of Particle Drifts . . . . .	51
4.3	Adiabatic Invariants . . . . .	51
4.3.1	Magnetic Moment, First Adiabatic Invariant . . . . .	52
4.3.2	Second (Longitudinal) Adiabatic Invariant . . . . .	53
4.3.3	Third (Drift) Adiabatic Invariant . . . . .	54
4.3.4	Violation of Adiabatic Invariants . . . . .	54
<b>5</b>	<b>The Inner Magnetosphere</b>	<b>55</b>
5.1	Trapped Particles . . . . .	55
5.1.1	Bounce Motion . . . . .	55
5.1.2	Particle Drift Motion . . . . .	57
5.1.3	Sources and Sinks of Ring Current Particles . . . . .	61
5.2	Ring Current . . . . .	61
5.2.1	Magnetic disturbance: . . . . .	62
5.2.2	Magnetic Storms . . . . .	63

<b>6</b>	<b>The Bow Shock and the Magnetosheath</b>	<b>65</b>
6.1	Solar Wind . . . . .	65
6.2	MHD Discontinuities and Shocks . . . . .	69
6.2.1	Rankine Hugoniot Conditions and MHD Discontinuities . . . . .	69
6.2.2	Hydrodynamic Shocks . . . . .	72
6.2.3	MHD Shocks . . . . .	74
6.3	Properties of the Bow Shock and the Magnetosheath . . . . .	82
6.3.1	Foreshocks and deHoffmann-Teller Frame . . . . .	82
6.3.2	Shock Structure and Heating . . . . .	84
6.3.3	Magnetosheath Flow and Structure . . . . .	86
<b>7</b>	<b>The Magnetopause</b>	<b>94</b>
7.1	Basic Properties and Observations . . . . .	96
7.1.1	Boundary Normal Coordinates and Variance Analysis . . . . .	96
7.1.2	Magnetopause Shape . . . . .	99
7.1.3	Magnetopause Motion, Thickness, and Plasma Properties . . . . .	101
7.2	Magnetopause Structure . . . . .	103
7.2.1	Open or Closed Magnetopause Configuration . . . . .	103
7.2.2	MP Currents . . . . .	105
7.3	Magnetic reconnection . . . . .	111
7.3.1	Reconnection models . . . . .	114
7.3.2	Sweet-Parker Reconnection . . . . .	116
7.3.3	Petschek Reconnection . . . . .	121
7.3.4	Application and Further Discussion of Magnetic Reconnection . . . . .	126
7.3.5	Observation of magnetopause reconnection . . . . .	132
7.3.6	Magnetopause Reconnection Models . . . . .	134
7.4	Viscous Interaction . . . . .	137
<b>8</b>	<b>Quiet Magnetotail</b>	<b>142</b>
8.1	Magnetotail models . . . . .	142
8.1.1	Magnetic field models . . . . .	142
8.1.2	Equilibrium Configuration . . . . .	143
8.2	Convection in the Magnetotail . . . . .	149

<b>9</b>	<b>Magnetospheric Substorms and Magnetosphere Ionosphere Coupling</b>	<b>152</b>
9.1	Magnetosphere-Ionosphere Coupling . . . . .	152
9.1.1	Currents and Convection in the Ionosphere . . . . .	152
9.2	Magnetospheric Substorm . . . . .	159
9.2.1	Growth Phase . . . . .	159
9.2.2	Expansion Phase . . . . .	165
9.2.3	Recovery Phase and Other Related Phenomena . . . . .	168
9.2.4	Steady Magnetospheric Convection . . . . .	168
<b>A</b>	<b>Appendix</b>	<b>169</b>
A.1	Bounce motion . . . . .	169
A.2	Evaluation of the gradient curvature drift in a dipolar magnetosphere . . . . .	170
A.3	Definition of the radius of curvature . . . . .	172
A.4	Kinetic Waves in a Magnetized Plasma . . . . .	173
A.5	Collisionless Waves in an Anisotropic Plasma . . . . .	178
A.6	Plasma Dispersion Function . . . . .	179
A.7	Bessel Functions and Modified Bessel Functions . . . . .	180