

TABLE OF CONTENTS

Preface

xvii

INTRODUCTION

R.L. Carovillano: THE SOLAR-TERRESTRIAL SYSTEM

1

SOLAR SYSTEM MAGNETOHYDRODYNAMICS: CONCEPTS AND BASIC EQUATIONS

G.L. Siscoe: SOLAR SYSTEM MAGNETOHYDRODYNAMICS

I. THE MACROSCOPIC EQUATIONS OF A PLASMA	11
From Particles to Fluids	11
Phase Space Density	12
The Continuity Equation in Phase Space	12
The Boltzmann Equation	13
Liouville's Theorem	14
Forming the Macroscopic Variables	14
Derivation of the Macroscopic Equations	14
The Field Equations	18
The Conservation Equations	20
Inclusion of Neutral Particle Interactions	22
The Prognostic Equation for Scalar Pressure	23
Temperature and Related Concepts	25
Return to the Prognostic Equation for Scalar Pressure	28
Adiabatic, Isentropic, and Polytropic Flows	29
The Bernoulli Equation	30
Divergence of the Anisotropic Pressure Tensor	31
Single Particle Drifts and the Euler Equation	32
Limitations to the Use of the Macroscopic Equations	37

II. THE HYDROMAGNETIC APPROXIMATION AND ITS CONSEQUENCES	38
The Generalized Ohm's Law	38
Charge Neutrality and Related Approximations	41
Poynting's Theorem in the Hydromagnetic Limit	43
Equipotential Fieldlines and Streamlines in Steady-State Hydromagnetic Flows	43
Freezing Laws	46
Thawing of Magnetic Flux	48
The Generalized Vorticity Theorem	50
The MHD Helmholtz Equation	52
The Double Adiabatic Invariants	53
III. MHD WAVES AND DISCONTINUITIES	57
Linearized Plane Waves in an Isotropic Magnetized Plasma	57
MHD Discontinuities	67
Shock Waves 1: Ordinary (non-MHD) Shock Waves	71
Shock Waves 2: Parallel Shocks	74
Shock Waves 3: Perpendicular Shocks	74
Shock Waves 4: Oblique Intermediate Mode Shocks	76
Shock Waves 5: Oblique Fast and Slow Mode Shocks	77
IV. MHD INSTABILITIES	80
The Firehose and Mirror Instabilities	80
The Kelvin-Helmholtz Instability	85
The Magnetospheric Interchange Instability	92
SOLAR AND INTERPLANETARY PHYSICS	
E.N. Parker: GENERATION OF SOLAR MAGNETIC FIELDS	101
Theories of Magnetic Field Origins	101
Induction Equations	104
Short-Sudden Approximation	108
Cyclonic Convection	113
Induction in the Earth	119
Other Dynamo Effects	122
Magnetic Field of the Sun	125
E.N. Parker: HEATING OF THE OUTER SOLAR ATMOSPHERE	129
The Solar Magnetic Field	129

Heating of the Corona	131
Model for Magnetic Merging	132
Idealized Problem	139
Application to the Sun	143
Alternative Mechanisms	152
Conclusion	152
 A. Barnes: HYDROMAGNETIC WAVES IN THE INTERPLANETARY MEDIUM	 155
Equations of Magnetohydrodynamics	156
An Exact Solution - Alfvenic Fluctuations	157
Classification of Wave Modes - Simple Waves	161
Geometrical Hydromagnetics	164
Alfven Wave Pressure	170
 A. Barnes: HYDROMAGNETIC TURBULENCE IN THE INTERPLANETARY MEDIUM	 172
Some Comments on the Theory of Fluid Turbulence	174
Rugged Invariants of Hydromagnetic Turbulence	179
Observed Alfvenic Fluctuations - Waves or Turbulence?	182
 A. Barnes: COLLISIONLESS PROCESSES IN THE INTERPLANETARY MEDIUM	 185
General Remarks on the Collisionless Kinetic Theory	185
Evolution of Velocity Distributions in Solar Wind Flow	190
Collisionless Waves, Damping, and Instability	193
 L.A. Fisk: SOLAR COSMIC RAYS - THEIR INJECTION, ACCELERATION, AND PROPAGATION	 201
Solar Flare Observations	202
The Injection	202
The Acceleration	207
The Propagation	208
 L.A. Fisk: SOLAR MODULATION OF GALACTIC COSMIC RAYS	 217
Solar-Cycle Variations	217
The Basic Idea	218
The Modulation Equations	219
Energy Loss	222
Solving the Modulation Equations	224
Some Illustrative Examples	226

L.A. Fisk: THE ACCELERATION OF ENERGETIC PARTICLES IN THE SOLAR WIND	231
Statistical Acceleration	231
Shock Acceleration	233
The Anomalous Component	237
MAGNETOSPHERIC PHYSICS	
V.M. Vasyliunas: LARGE-SCALE MORPHOLOGY OF THE MAGNETOSPHERE	243
Magnetic Field Structures	244
Plasma Structures	248
Low-Altitude Structures	252
V.M. Vasyliunas: MAGNETIC FIELD LINE MERGING; BASIC CONCEPTS	255
T.W. Hill: SOLAR-WIND MAGNETOSPHERE COUPLING	261
I. THE SOLAR WIND - AN ANISOTROPIC FLUID	262
II. MAGNETOSPHERIC CONVECTION	264
Frozen-in-Flux	264
The Axford-Hines Model	265
The Dungey Model	266
Open vs. Closed	269
Birkeland Currents	269
Substorms	271
III. MAGNETIC COUPLING	271
The Requirement for Magnetic Merging	271
Energy Flow in the Open Model	273
Momentum Transfer in the Open Model	280
Geometry	284
IV. NON-MAGNETIC COUPLING	288
Wave Transfer	288
Particle Transfer	288
Diffusion	292

V. THE TAIL	296
APPENDIX A - THE REQUIREMENT FOR RETURN FLOW	297
APPENDIX B - MEAN-SQUARE DISPLACEMENT IN CROSS-FIELD DIFFUSION	298
R.A. Wolf: THE QUASI-STATIC (SLOW-FLOW) REGION OF THE MAGNETOSPHERE	303
I. INTRODUCTION	303
II. QUALITATIVE OVERVIEW	305
Plasma Regions	305
Electric Currents	307
Dynamics of the Inner Magnetosphere	308
III. ADIABATIC INVARIANTS AND ADIABATIC DRIFTS	309
Adiabatic Invariants	309
Bounce-Averaged Drifts	314
IV. IONOSPHERE-MAGNETOSPHERE COUPLING	319
Pressure/Birkeland-Current Relation (from Drift Theory)	319
Pressure/Birkeland-Current Relation from MHD	321
Ionospheric Conductivity	324
A Fundamental Equation of Ionosphere-Magnetosphere Coupling	329
V. CALCULATIONS OF CONVECTION IN THE INNER MAGNETOSPHERE	329
Vasyliunas' Logical Loop	330
Simple Analytic Model	332
VI. COMPUTER MODEL OF INNER MAGNETOSPHERIC CONVECTION	342
Introductory Comments	342
Input to the Computer Models	344
Computer Models-Selected Results	345

VII. PARTICLE LOSS AND MAGNETIC FIELD MODELS	356
Loss of Particles from Magnetospheric Flux Tubes	356
Magnetic Field Models	359
Combined Convection and Magnetic-Field Models	364
C.C. Wu: GLOBAL MHD MODEL OF THE EARTH'S MAGNETOSPHERE	369
Global MHD Model	369
Numerical Methods	371
Results:	376
1. Shape of the Magnetosphere	380
2. Plasma Flow Patterns in the Magnetosphere	390
W.J. Burke and M. Heinemann: ORIGINS AND CONSEQUENCES OF PARALLEL ELECTRIC FIELDS	
I. INTRODUCTION	393
II. ORIGINS OF $E_{ }$	395
Anomalous Resistivity	397
Thermoelectric Effect	399
Quasi-neutral Potentials	400
Double Layers	406
III. CONSEQUENCES OF $E_{ }$	414
Field-Aligned Currents	414
Magnetospheric Models	416
A. Hasegawa: ELECTROSTATIC ION ACOUSTIC WAVES	
I. INTRODUCTION	425
II. LINEAR PROPERTIES	425
Electrostatic, Collisionless Ion Acoustic Wave	425
Effect of an Ambient Magnetic Field	429
Instability due to an Electron Drift	431
Instability due to a Decay of an Electromagnetic Wave	432
III. INCOHERENT NONLINEAR EFFECTS	435
Quasi Linear Effects	435
Nonlinear Mode Couplings	436

IV. COHERENT NONLINEAR EFFECTS	440
Ion Acoustic Shock	440
Ion Acoustic Solitons	442
Weak Double Layers	446
W.J. Hughes: HYDROMAGNETIC WAVES IN THE MAGNETOSPHERE	453
Introduction	453
HM Modes in Cold Plasma	454
The Effect of the Ionosphere	457
Field Line Resonance	460
Solution Along B	465
Resonances in Warm Plasmas	465
Field-Aligned Currents	466
Convection Flow and Alfvén Waves	469
Sources and Sinks of Wave Energy	472
V.M. Vasyliunas: COMPARATIVE MAGNETOSPHERES	
Introduction	479
Survey of Magnetospheres	480
Plasma Flow: Corotation and its Limits	486
Magnetospheric Distance Scales	490
P.H. Reiff: THE USE AND MISUSE OF STATISTICAL ANALYSES	
Why Use Statistics?	493
Confirmatory Studies	494
Exploratory Studies	495
Common-Sense Rules	496
Useful Statistical Techniques	499
Linear Correlation Analysis	500
Searching for Periodicities	506
Fourier Analysis	506
Superposed Epoch Analysis	509
Autocorrelation and Cross-Correlation Analyses	512
Autocorrelation	512
Power Spectral density	514
Cross-Correlation Analysis	514
Smoothing the Data	517

UPPER ATMOSPHERIC PHYSICS

A.D. Richmond: THERMOSPHERIC DYNAMICS AND ELECTRODYNAMICS	523
I. INTRODUCTION	523
II. BASIC EQUATIONS	526
Mass Continuity	526
Momentum Balance	527
Energy Balance	529
Pressure and Internal Energy	530
Diffusion	532
Viscosity	534
Heat Conduction	535
Electric Conductivities	536
III. LARGE-SCALE THERMOSPHERIC STRUCTURE AND DYNAMICS	539
Hydrostatic Equilibrium	540
Steady-State Thermal Structure	541
Thermospheric Heating	543
Mean Meridional Circulation of the Thermosphere	544
Steady-State Composition	544
Large-Scale Dynamics	547
Importance of Ion Drag	549
Importance of Viscosity	551
Computer Simulations of Thermospheric Dynamics	553
IV. ATMOSPHERIC WAVES	555
Entropy Equation	555
Pressure Change Equation	556
Linearized Perturbation Equations in a Plane	
Stratified Atmosphere	556
Wave Energy Equation	557
Two Simplified Limiting Cases	559
Dispersion Relation for Waves in a Dissipationless	
Atmosphere, Neglecting Rotation	561
Ducting	563
Vertical Energy Flux	564
Wave Energy Density	565
Properties of Long-Period Gravity Waves	566
Gravity Wave Energy Dissipation	567
Atmospheric Tides	569

V. ELECTRODYNAMICS	573
Basic Equations	574
Horizontal and Vertical Current Densities	576
Dynamo Action by Winds	577
Approximation of Infinitely Conducting Magnetic Field Lines	579
Dipole Coordinates	580
Solution for V	582
Equatorial Electrojet	584
VI. THERMOSPHERIC DISTURBANCES	586
Two-Dimensional Time-Dependent Model Description	587
Substorm Simulation	588
Electrodynamic Effects of Stormtime Heating	593
Energy Transfer to Lower Latitudes	595
Stormtime Composition Changes	599
Glossary of Symbols	601
R.W. Schunk: THE TERRESTRIAL IONOSPHERE	609
I. INTRODUCTION	609
II. IONOSPHERIC ENVIRONMENT	609
High-latitude Ionosphere	611
Mid-latitude Ionosphere	615
Low-latitude Ionosphere	618
Ionospheric Layers	620
III. THE THEORY	620
Transport Equations	621
Collision Terms	622
Collision Frequencies	623
Stress and Heat Flow Expressions	626
Photoionization	627
Chemical Reactions	632
Heating Rates	633
Cooling Rates	638
IV. MIDDLE AND LOW LATITUDE IONOSPHERE	639
Chapman Layer	640
Ambipolar Diffusion	640
Diffusive Equilibrium	642

Wind-induced Plasma Drift	643
Decay of the F-layer	643
Thermal Structure	644
Diurnal Variation of the Ionosphere	647
Solar Cycle Variation of the Ionosphere	649
Seasonal Variation of the Ionosphere	649
Ionospheric Behavior at Low Latitudes	651
 V. HIGH LATITUDE IONOSPHERE	 651
Plasma Convection	652
Magnetospheric Convection Pattern	654
Electron Density Morphology	656
Effect of Electric Fields on Ion Temperature	659
Effect of Electric Fields on Ion Composition	663
 VI. POLAR WIND	 663
Subsonic H^+ Outflow	663
Supersonic H^+ Outflow	666
Hydrodynamic Solutions	669
Collisionless Solutions	670
Self-Similar Solutions	672
 J.R. Winick: PHOTOCHEMICAL PROCESSES IN THE MESOSPHERE AND LOWER THERMOSPHERE	 677
 I. PHYSICAL AND CHEMICAL CONCEPTS	 677
The Hydrostatic Law	679
Transport Processes	681
Photochemical Production and Loss	684
Absorption of Solar Flux	690
Calculation of Photodissociation Rates	698
 II. THE ONE-DIMENSIONAL CONTINUITY EQUATION IN THE UPPER MESOSPHERE	 699
The Chemistry of HO_x and O_x	702
Production of Nitric Oxide	711
Atomic Oxygen Profile	713
 III. ION CHEMISTRY	 715
The Lower E-Region	715
The D-Region	719

Cluster Ions in the D-Region	720
D-Region Negative Ion Chemistry	725
The Disturbed D-Region	728
 J.M. Forbes: PHYSICS OF THE MESOPAUSE REGION	 733
I. CHARACTERISTICS OF THE MESOPAUSE REGION	733
Thermal and Dynamical Structure	733
Physical Processes	735
 II. SOME FUNDAMENTAL DYNAMICS	 738
The Perturbation Approach (Linearization)	738
Thermal Wind Balance	740
Wave-Mean Flow Interactions	741
 III. RADIATIVE COOLING NEAR THE MESOPAUSE	 742
Simple Radiative Transfer	742
Non-LTE and Collisional Relaxation	744
The 'Cooling to Space' and 'Newtonian Cooling' Approximations	745
 IV. ZONAL MEAN LATITUDE STRUCTURE	 747
Radiative and Thermal Budgets	747
Radiative-Dynamical Balance and the Possible Role of Wave Stress	748
 M.H. Rees: AURORAL EXCITATION AND ENERGY DISSIPATION	 753
Introduction	753
Penetration of Auroral Electrons into the Atmosphere	754
Inelastic Scattering	758
Electron Intensity and Energy Deposition	761
Excitation by Electron Impact	763
Auroral Ion Chemistry and Transport	765
Chemical Excitation	769
Theory of the Auroral Spectrum	770
Dissipation of Auroral Energy	773
Auroral Protons	776
Summary	777

S.T. Zalesak: SMALL-SCALE STRUCTURE IN THE EARTH'S IONOSPHERE: THEORY AND NUMERICAL SIMULATION	781
Introduction	781
The Gradient Drift/Collisional Rayleigh-Taylor Instability	785
The Motion of Ionospheric Plasma	787
Model Simplification and Mathematical Representation	791
The Simplest Case Equations for Barium Clouds and for ESF	794
Numerical Simulation: General	795
The Numerical Solution of the Potential Equation	797
The Numerical Solution of the Continuity Equation	798
 T.E. Cravens: COMPARATIVE IONOSPHERES	 805
I. THE INNER PLANETS	805
Introduction	805
Neutral Atmosphere	807
Solar Wind-Ionosphere Interaction	811
The Dayside Ionosphere: Basic Equations	815
The Dayside Ionosphere: Composition	816
The Dayside Ionosphere: Energetics	820
The Nightside Ionosphere	822
 II. THE OUTER PLANETS	 825
Introduction	825
Jupiter and Saturn: Thermosphere Composition and Temperature Structure	826
Jupiter and Saturn: Thermosphere Hydrocarbons and Atomic Hydrogen	828
Jupiter and Saturn: The Ionosphere	834
The Jovian Satellite Io	837
The Saturnian Satellite Titan	837
Comets	839
 SUBJECT INDEX	 845

