

# Physics of the Plasma Universe

Anthony L. Peratt

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With 208 Figures



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## Preface

The purpose of this book is to address the growing recognition of the need for plasma physics in astrophysics. In fact, astrophysics has contributed to the growth of plasma physics, especially in the field of plasma waves. During the last decade, plasma physics, or more appropriately, plasma science, has witnessed an explosive growth in two areas: pulsed-power technology and space physics. Both have led to knowledge that is mutual and complementary, and the material in this book largely derives from these new discoveries and their application to astrophysics. With the passage of the Voyager spacecraft in 1989, Neptune was transformed from an astronomical object to a space science object. In our solar system, only Pluto remains unvisited. In this decade of exploration, the solar system has become recognized as the primary plasma laboratory in which plasma processes of great generality and astronomical significance can be studied in situ. By the 1960s, with the discovery of the earth's natural plasmas, the Van Allen radiation belts, and the solar wind, it was already clear that future understanding of the earth and sun would be expressed in terms of plasmas. Today plasma is recognized as the key element to understanding the generation of magnetic fields in planets, stars, and galaxies; phenomena occurring in stellar atmospheres, in the interstellar and intergalactic media, in radio galaxies, in quasars, and in active galactic nuclei; and the acceleration and transport of cosmic rays. There are convincing arguments for the view that the clouds out of which galaxies form and stars condense are ionized: The problem of the formation and structure of these clouds and bodies, therefore, naturally belongs to the field of cosmic plasmas as well as astrophysics. Each has traditionally been pursued independently. Only recently has there been a tendency to view them as a unified discipline.

Together these problems form what is called *The Plasma Universe*, the basis for this book. The material presented dwells basically on the known properties of matter in the plasma state. Some of the interesting topics in contemporary astrophysics such as discordant redshifts and other cosmological issues are not discussed here. The interested reader will be referred to the *IEEE Transactions on Plasma Science*, Special Issues on Space and Cosmic Plasmas (December 1986, April 1989, and February 1990), and *Laser and Particle Beams* (August 1988).

This book is organized into eight chapters. Chapter 1 is an introduction to the fundamental physics of cosmic plasmas. An attempt is made to review the known properties of plasmas from the laboratory scale to the Hubble distance. Chapter 2

starts the application of basic plasma theory to astrophysical plasmas in the study of magnetic-field-aligned (Birkeland) currents and charged particle beams. Chapter 3 covers magnetism in plasma and the Biot–Savart force law, while Chapter 4 concentrates on electric fields in space and cosmic plasmas. Chapters 5, 6, and 7 survey double layers, synchrotron radiation, and energy transport in plasmas, respectively. Chapter 8 covers the particle-in-cell simulation of astrophysical plasmas. Found throughout the book are examples that apply the material of the chapter or section to specific problems.

At the end of the book are appendixes highlighting topics that are often not covered in plasma physics or in astrophysics texts, or else are well-documented to the point that a short condensation suffices. Appendix A covers transmission line concepts in space plasmas. Appendix B is a condensation of the polarization properties of plasma waves. In Appendix C dusty and grain plasmas are discussed.

A list of references is given for each chapter. These are divided into parts: General references give a list of papers and books that cover the general aspects and that often give a more thorough treatment of the subjects covered, and special or specialized references document the sources for specific topics.

As far as possible, the equations are written to conform to SI regulations, but since this book deals with the plasma universe whose elements transcend many disciplines, from laboratory controlled fusion experiments to cosmology, a multitude of non-SI units are used. For example, it is customary in the laboratory to state densities in particles per cubic centimeter and magnetic induction in gauss, rather than in particles per cubic meter and tesla, as used in space plasmas. Likewise, units of light-years and parsecs are more meaningful to describe the dimensions of galaxies and clusters of galaxies than are meters. To aid visualization, both SI and familiar units are often given in the text.

This book could not have been written without the help and encouragement of many friends and colleagues. I am grateful to my collaborators at the Royal Institute of Technology, Stockholm, whose work I have freely drawn upon: Drs. C.-G. Fälthammar, P. Carlqvist, M. Raadu, L. Block, N. Brenning, S. Torvén, L. Lindberg, and M. Bohm. I am appreciative to my colleagues at Los Alamos: Drs. S. Gitomer, G. Nickel, R. Faehl, R. Shannahan, A. Greene, M. Jones, G. Gisler, B. Freeman, R. Keinigs, J. Borovosky, E. Lindman, A. Cox, and D. Lemons. Thanks are also due to Drs. H. Kuehl, A. Dessler, T. Potemra, G. Reber, R. Beck, P. Marmet, W. Bostick, V. Nardi, F. Gratton, B. Meierovich, A. Crusius-Wätzel, N. Rostocker, T. Eastman, J.-P. Vigier, E. Witalis, E. Wollman and N. Salingaros. I am especially indebted to O. Buneman, J. Green, C. Snell, W. Peter, E. Lerner, and H. Alfvén for their constant encouragement. Last, my wife, Glenda, and children, Sarah, Galvin, and Mathias, should not be forgotten for the time given to complete this book.

Los Alamos, New Mexico

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# Contents

Preface .....	v
1. Cosmic Plasma Fundamentals .....	1
1.1 Plasma .....	1
1.2 The Physical Sizes and Characteristics of Plasmas in the Universe .....	2
1.2.1 Plasmas on Earth .....	2
1.2.2 Near-Earth Plasmas .....	4
1.2.3 Plasmas in the Solar System .....	8
1.2.4 Transition Regions in the Solar System .....	10
1.2.5 Solar, Stellar, and Interstellar Plasmas .....	10
1.2.6 Galactic and Extragalactic Plasmas .....	16
1.3 Regions of Applicability of Plasma Physics .....	17
1.4 Power Generation and Transmission .....	20
1.5 Electrical Discharges in Cosmic Plasma .....	22
1.6 Particle Acceleration in Cosmic Plasma .....	23
1.6.1 Acceleration of Electric Charges .....	23
1.6.2 Collective Ion Acceleration .....	23
1.7 Plasma Pinches and Instabilities .....	26
1.7.1 The Bennett Pinch .....	26
1.7.2 The Force-Free Configuration .....	28
1.7.3 The Diocotron Instability .....	29
1.7.4 Critical Ionization Velocity .....	30
1.8 Diagnosing Cosmic Plasmas .....	33
1.8.1 The Electromagnetic Spectrum .....	33
1.8.2 In Situ Space Probes .....	39
2. Birkeland Currents in Cosmic Plasma .....	43
2.1 History of Birkeland Currents .....	43
2.2 Field-Aligned Currents in Laboratory Plasma .....	47
2.3 Field-Aligned Currents in Astrophysical Plasmas .....	48
2.4 Basic Equations of Magnetohydrodynamics .....	49
2.4.1 General Plasma Fluid Equations .....	49
2.4.2 Magnetic Reynolds and Lundquist Numbers .....	51
2.5 The Generalized Bennett Relation .....	52
2.5.1 The Bennett Relation .....	55
2.5.2 Alfvén Limiting Current .....	55

2.5.3	Charge Neutralized Beam Propagation	56
2.5.4	Current Neutralized Beam Propagation	57
2.5.5	Discussion	57
2.5.6	Beam Propagation Along an External Magnetic Field	58
2.5.7	Schönherr Whirl Stabilization	58
2.5.8	The Carlqvist Relation	58
2.5.9	The Cylindrical Pinch	59
2.5.10	The Sheet Pinch	61
2.6	Application of the Carlqvist Relation	62
2.6.1	Birkeland Currents in Earth's Magnetosphere	62
2.6.2	Currents in the Solar Atmosphere	63
2.6.3	Heliospheric Currents	64
2.6.4	Currents in the Interstellar Medium	65
2.6.5	Currents in the Galactic Medium	66
2.6.6	Currents in the Intergalactic Medium	66
2.7	Basic Fluid and Beam Instabilities	67
2.7.1	Jeans Condition for Gravitational Instability	67
2.7.2	Two-Stream (Buneman) Instability	68
2.7.3	Sausage and Kink Instabilities	70
2.8	Laboratory Simulation of Cosmic Plasma Processes	71
2.8.1	High-Current Plasma Pinches	72
2.8.2	Laboratory Aurora Simulations	74
2.9	The Particle-in-Cell Simulation of Beams and Birkeland Currents	76
2.9.1	Charge and Current Neutralized Beam Propagation in Plasma	77
2.9.2	Relativistic and Mildly Relativistic Beam Propagation in Plasma	78
2.9.3	Propagation of a Relativistic Beam Bunch Through Plasma	79
2.9.4	Beam Filamentation	79
2.9.5	Dynamical Evolution of a Narrow Birkeland Filament	80
2.9.6	Vortex Formation in Thin Cylindrical Electron Beams Propagating Along a Magnetic Field	84
2.9.7	Charge-Neutralized Relativistic Electron Beam Propagation Along a Magnetic Field	87
2.9.8	Numerical Aurora Simulations	89
3.	Biot-Savart Law in Cosmic Plasma	93
3.1	History of Magnetism	93
3.2	The Magnetic Interaction of Steady Line Currents	94
3.3	The Magnetic Induction Field	95
3.3.1	Field from an Infinite Conductor of Finite Radius	96
3.3.2	Force Between Two Infinite Conductors	97
3.4	The Vector Potential	99
3.4.1	Field from a Circular Loop and Force Between Two Circular Loops	99
3.4.2	Force Between Two Circular Loops Lying in a Plane	101
3.5	Quasi-Stationary Magnetic Fields	101
3.5.1	Faraday's Law	102
3.5.2	Motion Induced Electric Fields	103
3.5.3	Faraday Disk Dynamo	104

3.6	Inductance	104
3.7	Storage of Magnetic Energy	106
3.7.1	Energy in a System of Current Loops	106
3.7.2	In Situ Storage in Force Free Magnetic Field Configurations	107
3.8	Forces as Derivatives of Coefficients of Inductance	108
3.9	Measurement of Magnetic Fields in Laboratory Plasmas	108
3.10	Particle-in-Cell Simulation of Interacting Currents	110
3.10.1	Simulation Setup	111
3.10.2	Initial Motion of Current Filaments	111
3.10.3	Polarization Forces	113
3.10.4	Magnetic Energy Distribution and Magnetic Isobars	113
3.10.5	Net Motion	119
3.10.6	“Doubleteness” in Current-Conducting Plasmas	119
3.11	Magnetic Fields in Cosmic Dimensioned Plasma	119
3.11.1	Measurement of Galactic Magnetic Fields	119
3.11.2	Milky Way Galaxy	122
3.11.3	Spiral Galaxies	126
3.11.4	Rotational Velocities of Spiral Galaxies	128
3.11.5	Elliptical Galaxies	131
3.11.6	Intergalactic Magnetic Fields	135
4.	Electric Fields in Cosmic Plasma	137
4.1	Electric Fields	137
4.2	Measurement of Electric Fields	138
4.3	Magnetic Field Aligned Electric Fields	143
4.3.1	Collisionless Thermoelectric Effect	143
4.3.2	Magnetic Mirror Effect	144
4.3.3	Electrostatic Shocks	145
4.3.4	Electric Double Layers	146
4.4	Magnetospheric Electric Fields	146
4.4.1	The Plasmasphere	146
4.4.2	The Plasmasheet	147
4.4.3	The Neutral Sheet	149
4.4.4	The Magnetotail	149
4.4.5	The Magnetopause	149
4.4.6	The Auroral Acceleration Region	149
4.4.7	Global Distributions of Auroral Electric Fields	153
4.5	Outstanding Questions	154
4.6	Phenomena Associated with Electric Fields	156
4.6.1	Surface Discharges	156
4.6.2	Plasma Gun Arc Discharges	156
4.6.3	Marklund Convection and Separation of Elements	165
4.6.4	Particle Acceleration and Runaway	168
4.6.5	Field-Aligned Electric Fields as the Source of Cosmic Rays	170
5.	Double Layers in Astrophysics	171
5.1	General Description of Double Layers	171



5.2	The Time-Independent Double Layer .....	173
5.2.1	One-Dimensional Model .....	173
5.2.2	Ratio of the Current Densities .....	175
5.2.3	The Potential Drop .....	176
5.2.4	Structure of the Double Layer .....	176
5.2.5	Kinetic Description .....	176
5.3	Particle-in-Cell Simulation of Double Layers .....	179
5.3.1	Simulations of the Two-Stream Instability .....	180
5.3.2	Simulations of Double Layers .....	182
5.4	Double Layers in Current Filaments .....	183
5.5	Basic Properties of Double Layers .....	185
5.5.1	Double Layers as a Surface Phenomena .....	185
5.5.2	Noise and Fluctuations in Double Layers .....	186
5.5.3	Exploding Double Layers .....	186
5.5.4	Oblique Double Layers .....	188
5.6	Examples of Cosmic Double Layers .....	188
5.6.1	Double Layers in the Auroral Circuit .....	188
5.6.2	Solar Flares .....	191
5.6.3	Double Radio Galaxies and Quasars .....	194
5.6.4	Double Layers as a Source of Cosmic Radiation .....	195
6.	Synchrotron Radiation .....	197
6.1	Theory of Radiation from an Accelerated Charge .....	198
6.1.1	The Induction Fields .....	199
6.1.2	The Radiation Fields .....	201
6.2	Radiation of an Accelerated Electron in a Magnetic Field .....	207
6.2.1	Angular Distribution of the Radiation .....	211
6.2.2	Frequency Distribution of the Radiation .....	213
6.3	Field Polarization .....	219
6.3.1	Polarization in the Plane of Rotation .....	219
6.3.2	Polarization for Arbitrary Angles of Observation .....	220
6.4	Radiation from an Ensemble of Electrons .....	222
6.4.1	Velocity-Averaged Emissivity .....	222
6.4.2	Emission from an Ensemble of Electrons .....	227
6.5	Synchrotron Radiation from Z Pinches .....	229
6.5.1	X Ray Emission .....	229
6.5.2	X Ray Spectroscopy .....	230
6.5.3	Morphology of the Thermal X Ray Source .....	230
6.6	Particle-in-Cell Simulation of Synchrotron Processes .....	233
6.6.1	Simulated Z Pinches .....	233
6.6.2	Synchrotron Bursts from Simulated Z Pinches .....	234
6.6.3	Synchrotron Source Radiation Patterns .....	236
6.7	Synchrotron Radiation from Cosmic Sources .....	236
6.7.1	Gross Radio Properties of Galaxies .....	236
6.7.2	Double Radio Galaxies .....	240
6.7.3	“Jets” and Superluminality .....	244
6.7.4	Quasars and Active Galaxy Nuclei .....	248
6.7.5	X Ray and Gamma-Ray Sources .....	251

7. Transport of Cosmic Radiation .....	253
7.1 Energy Transport in Plasma .....	254
7.1.1 Group Velocity .....	256
7.1.2 Time Rate of Decay of Wave Oscillations .....	262
7.2 Applications of Geometrical Optics .....	262
7.2.1 Basic Principle and Limitations of Geometrical Optics .....	262
7.2.2 Equation of Transfer .....	267
7.3 Black Body Radiation .....	270
7.4 The Source Function and Kirchoff's Law .....	272
7.4.1 Classical Limit of the Emission, Absorption, and Source Functions ...	273
7.5 Self Absorption by Plasma Filaments .....	275
7.6 Large-Scale, Random Magnetic Field Approximation .....	277
7.6.1 Plasma Effects .....	279
7.6.2 Monoenergetic Electrons .....	280
7.7 Anisotropic Distribution of Velocities .....	281
8. Particle-in-Cell Simulation of Cosmic Plasma .....	285
8.1 "In-Situ" Observation of Cosmic Plasmas via Computer Simulation .....	285
8.2 The History of Electromagnetic Particle-in-Cell Simulation .....	286
8.3 The Laws of Plasma Physics .....	287
8.4 Multidimensional Particle-in-Cell Simulation .....	288
8.4.1 Sampling Constraints in Multidimensional Particle Codes .....	288
8.4.2 Discretization in Time and Space .....	289
8.4.3 Spectral Methods and Interpolation .....	291
8.5 Techniques for Solution .....	292
8.5.1 Leap-Frogging Particles Against Fields .....	293
8.5.2 Particle Advance Algorithm .....	294
8.5.3 Field Advance Algorithm .....	295
8.6 Issues in Simulating Cosmic Phenomena .....	296
8.6.1 Boundary Conditions .....	296
8.6.2 Relativity .....	296
8.6.3 Compression of Time Scales .....	297
8.6.4 Collisions .....	297
8.7 Gravitation .....	299
8.8 Scaling Laws .....	300
8.9 Data Management .....	301
8.10 Further Developments in Plasma Simulation .....	302
Appendix A. Transmission Line Fundamentals in Space and Cosmic Plasmas .....	305
A.1 Transmission Lines .....	305
A.2 Definition of the State of the Line at a Point .....	305
A.3 Primary Parameters .....	306
A.4 General Equations .....	307
A.4.1 The General Case .....	307
A.4.2 The Special Case of the Lossless Line .....	308

A.5 Heaviside's Operational Calculus (The Lapace Transform) .....	309
A.5.1 The Propagation Function .....	309
A.5.2 Characteristic Impedance .....	311
A.5.3 Reflection Coefficients .....	312
A.6 Time-Domain Reflectometry .....	314
Appendix B. Polarization of Electromagnetic Waves in Plasma .....	317
Appendix C. Dusty and Grain Plasmas .....	325
C.1 Dusty Plasma .....	325
C.2 Grain Plasma .....	326
Appendix D. Some Useful Units and Constants .....	331
Appendix E. TRISTAN .....	335
References .....	345
Index .....	363