This book provides a comprehensive introduction to the theory of magnetic field line reconnection, now a major subject in plasma physics. The book focuses on the various reconnection mechanisms dominating magnetic processes under the different plasma conditions encountered in astrophysical systems and in laboratory devices. The book consists of two major parts: the first deals with the classical resistive approach, while the second presents an overview of weakly collisional or collisionless plasmas. Applications primarily concern astrophysical phenomena and dynamo theory, with emphasis on the solar dynamo and the geodynamo, as well as on magnetospheric substorms, the most spectacular reconnection events in the magnetospheric plasma. The theoretical procedures and results also apply directly to reconnection processes in laboratory plasmas, in particular the sawtooth phenomenon in tokamaks.

The book will be of value to graduate students and researchers interested in magnetic processes both in astrophysical and laboratory plasma physics.

Dieter Biskamp received his Ph.D. from the University of Munich. Following a postdoctoral period at the Max-Planck-Institute for Astrophysics he worked at the Space Research Institute in Frascati and became senior research scientist at the Max-Planck-Institute for Plasma Physics in 1972. Since 1981 he has been head of the General Theory Group and since 1995 has been head of the Nonlinear Plasma Dynamics Group. In 1979 he was visiting professor at the University of Texas and in 1995 COE visiting professor at the National Institute for Fusion Science in Nagoya. His scientific activities cover many areas of plasma physics, in particular magnetohydrodynamics and reconnection theory. He is the author of the book *Nonlinear Magnetohydrodynamics.*

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Magnetic Reconnection in Plasmas

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To the memory of my parents

Contents

Preface

This book is in a sense a sequel to my previous book *Nonlinear Magnetohydrodynamics*, which contained a chapter on magnetic reconnection. Judging from many discussions it appeared that it was this chapter that was particularly appreciated. The plan to write a full monograph on this topic actually took a concrete shape during a stay at the National Institute for Fusion Science at Nagoya, where I found the time to work out the basic conception of the book. It became clear that resistive theory, to which most of the previous work was restricted, including that chapter of my previous book, covers only a particular aspect of this multifaceted subject and not even the most interesting one, in view of the various applications, both in fusion plasma devices and in astrophysical plasmas, where collisionless effects tend to dominate over resistivity.

While resistive reconnection theory had reached a certain level of maturity and completion about a decade ago (few theories are really complete before becoming obsolete), the understanding of collisionless reconnection processes has shown a rapid development during the past five years or so. The book therefore consists of two main parts, chapters 3–5 deal with resistive theory, while chapters 6–8 give an overview of the present understanding of collisionless reconnection processes. I mainly emphasize the reconnection mechanisms, which operate under the different plasma conditions, to explain the apparent paradox that formally very weak effects in Ohm's law account for the rapid dynamic time-scales suggested by the observations.

Applications concern primarily astrophysical phenomena. Chapter 5 introduces dynamo theory, considering in some detail the generation of the solar and the geomagnetic field, while chapter 8 deals with magnetospheric substorms, the most important reconnection process in the Earth's magnetosphere. Both chapters are rather autonomous and can be read independently of the remainder of the book. Concerning laboratory plasmas I resume the discussion of the sawtooth phenomenon considered in some length in *Nonlinear Magnetohydrodynamics*, giving an update of the experimental and theoretical situation. I also discuss briefly several laboratory experiments designed specifically to study magnetic reconnection physics.

It is a pleasure to express my gratitude to the many colleagues with whom I enjoyed fruitful and illuminating discussions on the topics of this book, in particular Jim Drake, who taught me the importance of collisionless reconnection, and Wolfgang Baumjohann, Michael Hesse and Manfred Scholer for introducing me to the realm of magnetospheric physics. I also acknowledge the financial support by the COE programme of Monbusho and the kind hospitality of the National Institute for Fusion Science with special thanks to Tetsuya Sato. Finally I would like to thank Brian Watts for his painstaking copy-editing of the manuscript.

Garching, January 2000 *Dieter Biskamp*