P.Lorrain, F.Lorrain, S.Houle, "Magneto-Fluid Dynamics"
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# Preface

Magnetohydrodynamics (MHD) concerns the interaction between magnetic fields and conducting fluids. We are concerned here with macroscopic interactions and, when the conducting fluid is a plasma, time scales are very much longer than the plasma period. Plasma periods vary widely, but are short, say $10^{-10}$ second.

We prefer the term Magneto-*Fluid*-Dynamics (MFD) because the discipline concerns mostly plasmas, various liquid conductors, and the liquid part of the Earth's core. It seems that the only applications of MFD to water are the induction of electric currents in the oceans by the Earth's magnetic field, and ship propulsion. But even MFD is not quite appropriate because that term also includes solid conductors that move in magnetic fields.

This book is meant for graduate and upper-division undergraduate students in Physics, Geophysics, and Astrophysics, as well as for practicing scientists in these fields.

This book is no more than a brief *introduction* to MFD because this vast subject is closely related to many others, namely Astrophysics, Electrodynamics, Fluid Dynamics, Geophysics, Oceanography, Plasma Physics, Thermonuclear Fusion, etc. We sketch the fundamentals, and provide many Examples, as well as Case Studies related to natural phenomena.

MFD sorely needs a rethink: it must of course be totally compatible with Physics. On the contrary, it is the custom to discuss the shapes of imaginary magnetic field lines, without ever referring to the required electric currents. This fundamental error leads to much nonsense. Of course, a given magnetic field $\boldsymbol{B}$ and its specific current distribution, of current density $\boldsymbol{J}$, are not distinct quantities: the magnetic field is just one property of the current distribution. Moreover, because of Ohm's law for moving conductors (Chapter 6), $\boldsymbol{J}$ is a function of $\boldsymbol{B}$! Indeed, the $\boldsymbol{J}$ that generates the $\boldsymbol{B}$ field depends on $\boldsymbol{B}$ in three different ways. Even the electric potential $V$ is a function of $\boldsymbol{v} \times \boldsymbol{B}$, as in Chapter 7.

Here, we focus our attention on the current density $\boldsymbol{J}$. Our approach leads to new results, and disproves a number of misconceptions.

Hannes Alfvén, who was possibly the most prominent figure of Magneto-Fluid-Dynamics in the twentieth century, often stressed the importance of considering electric currents in MFD phenomena. Geophysicists and Astrophysicists should re-read Alfvén:

> *[In pseudo-MHD,] the electric current is traditionally eliminated, so that it does not appear explicitly, [so that] the formalism is not suited for describing phenomena associated with currents [...] Most serious is that the transfer of energy cannot be described in an adequate way [...] The "field line reconnection" concept is misleading [...] Frozen-in picture is often completely misleading [...] The transfer of energy [... is] lost. This has disastrous consequences [...] a better understanding [...] is possible if we derive the current system [...] Forgetting the "frozen-in" picture [...] We have no use for "magnetic field line reconnection" [...] this monstrous concept is a product of the frozen-in picture* in absurdum *[... etc.]*
> (Alfvén, 1943, 1975, 1981; Alfvén and Fälthammar, 1963)

Unfortunately, Alfvén's admonitions have gone unheeded.

Also, in our approach to MFD we take into account the electric field $-\nabla V$ of the space, or volume, charges *inside* conductors that move in magnetic fields. Although this electric field is hugely important, it is invariably ignored. That field is important because it opposes, and even cancels, the more prominent $\boldsymbol{v} \times \boldsymbol{B}$ field. Disregarding this space charge leads to absurd situations.

Finally, our approach is different in that we calculate numerical values, whenever possible.

This book comprises 16 chapters, each one preceded by its Table of Contents and a short introductory text, and followed by a Summary. Chapters 2 to 8 provide many Examples. Chapters 9 to 16 are Case Studies. Some of these Case Studies concern thought experiments, while the others concern natural magnetic fields. Two Appendices follow.

The book comprises five parts. We sketch here the overall structure; for further details, see "Looking Ahead", after this Preface.

There is a certain amount of repetition in the Case Studies because they are not meant to be read in precisely the same order as they are in the book.

**Part I, The Early History** (Chapter 1), is a brief historical introduction.

**Part II, Fundamentals** (Chapters 2 to 5), sketches the fundamentals of electromagnetic fields. These chapters are meant as a review, but *it is essential to master this material thoroughly before proceeding further.* The Examples relate largely to the material in the chapters that follow.

Readers who wish to delve more deeply into the basic principles of electromagnetic fields can refer to three other books by the undersigned and colleagues, all published by W.H. Freeman, New York: *Electromagnetic Fields and Waves* (third edition 1988), *Electromagnetism: Principles and*