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SPACE PLASMA—THE FOURTH STATE OF MATTER

MAGNETOSPHERIC CURRENTS

Thomas A. Potemra, Editor, *The Johns Hopkins University Applied Physics Laboratory*
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QUANTITATIVE ASPECTS OF MAGNETOSPHERIC PHYSICS

Lawrence R. Lyons, *Aerospace Corporation*, and
Donald J. Williams, *The Johns Hopkins University Applied Physics Laboratory*
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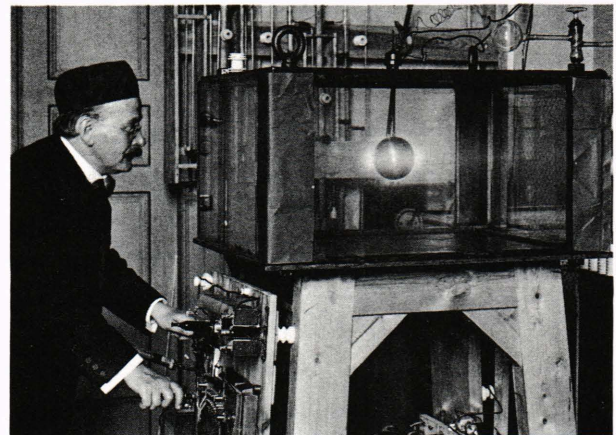
Research on magnetospheric plasma and, by implication, cosmic plasma in general depends on three factors: competent planning and deployment of space missions, sophisticated analysis of the data, and theoretical interpretation of the results. It is the combination of these three factors by a strong leadership that has given The Johns Hopkins University Applied Physics Laboratory its unique position in the world of cosmic plasma physics. This position has been clearly demonstrated by two recent publications: *Magnetospheric Currents*, a report of the Chapman Conference in Irvington, Va., in April 1983, organized by T. A. Potemra, and *Quantitative Aspects of Magnetospheric Physics*, a monograph by L. R. Lyons and D. J. Williams.

An important breakthrough in cosmic plasma physics was the mapping of the auroral current system by A. J. Zmuda and his collaborators¹ at APL about twenty years ago. The interaction of a magnetized central body with a surrounding plasma is a major problem in cosmic plasma physics, with applications to the theory of the evolution of the solar system and to several other important astrophysical problems. Arguments for an electromagnetic transfer of momentum were made long ago but were strongly opposed by astrophysicists who claimed that turbulence was the only possible mechanism of transfer. The observational demonstration of the existence of the required current system was a very important argument for an electromagnetic transfer, which is now confirmed by

results from other magnetospheres and supplemented by studies of the Jupiter-Io current system. (However, many, if not most, astrophysicists have still not accepted this.)

Zmuda's work has been continued by Iijima and Potemra,² so it was natural that the APL group should organize the Chapman Conference on electric currents in the magnetosphere. The symposium was important because it drew attention to the fact that it is impossible to understand the properties of a cosmic plasma without accounting explicitly for the electric current. The need for this accounting has been denied for decades by a powerful establishment that wanted to have all magnetospheric phenomena expressed in terms of magnetic fields and all energy transfer expressed in terms of merging or reconnections of magnetic field lines. This meant that the conference was a reaffirmation of the Birkeland approach to what we now call cosmic plasma phenomena.

The conference started with a lecture by Alf Egeland, who described Kristian Birkeland and his remarkable achievements. Later, A. J. Dessler gave an interesting lecture about the relationship between the Birkeland and the Sidney Chapman approaches. Dessler was the first to understand that Zmuda's measurements made the decision between the Chapman-Vestine and the Birkeland models in favor of the lat-



Birkeland in his terrella-laboratorium in 1905. His personal wealth allowed him to engage assistants and buy new equipment for the laboratory.

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ter.³ He started the rehabilitation of Birkeland by coining the term “Birkeland currents,” which soon was generally accepted. His lecture at the conference was a historical account of the fight between the Chapman and the Birkeland approaches to magnetospheric physics. This is of interest not only from the point of view of science history, but also because it is impossible to understand the present situation in magnetospheric physics unless one understands how the theoretical interpretation of the observational results was sidetracked by the authority of Chapman. The Chapman-Ferraro theory, the Chapman-Vestine system of currents, and the Chapman-Cowling theory of ionized gases have delayed progress by decades.

Dessler’s conclusion was that the Birkeland approach should be the basis of magnetospheric research; the symposium shows clearly that this approach is receiving rapid general acceptance. (This does not mean that the Chapman-Cowling formalism is useless; there are many cases when it is of considerable value, but its sacrosanct dominance is gone forever.)

From the planning of the symposium, it is evident that all the papers dealt with the need to account explicitly for electric currents in the magnetosphere. However, not all the papers clarified that Kirchhoff’s law is valid, i.e., that all currents must close. In other words, it is necessary for the whole circuit in which a current flows to be depicted, and the electromotive force that energizes the circuit (drives the current) must be located. The case when the circuit is energized by a dynamo $\Delta V = \int \mathbf{V} \times \mathbf{B} \cdot \mathbf{s}$ is very important, as is pointed out clearly by Akasofu (p. 43, Fig. 13), by Stern (p. 201, Figs. 2 and 7) in Hiekkilä’s models, by Block, and by Atkinson. A systematic introduction of circuits and dynamos will probably simplify magnetospheric theory and clarify how energy is transferred from the solar wind to the magnetosphere-ionosphere. Two papers by Cole on dielectric and permeability effects are also very interesting.

The need to supplement an exclusive field description by an explicit description in terms of particles and currents has slowly begun to be understood during the past five or ten years, but the first systematic treatment is by Lyons and Williams in their book, *Quantitative Aspects of Magnetospheric Physics*. They base their treatment of the motion of particles essentially on the guiding center method, and they elaborate that approach in detail and clarify the limitations of the method. Their monograph is an impressive treatment

of an overwhelmingly rich body of observational material from the point of view of particles and currents.

In their preface they say: “We have avoided controversial and relatively new research topics and have tried to use as examples physical processes generally accepted as important within the earth’s magnetospheric system.” This is a good principle, and they live up to it, perhaps even too much. For example, in many cases they depict the circuit in which a current flows, but sometimes (e.g., in Fig. 4.43) they show only a part of the current without clarifying how it closes. This cannot be called “controversial” nor is it new (it derives from Kirchhoff!), but by that omission they fail to locate the current-driving electromotive force, which often is a dynamo. This means that the long-distance transfer of energy by electric currents is not included. The reader gets the impression that the state of plasma can be described by *local* theories, whereas, in reality, it is necessary to apply *global* theories, including the whole region that is penetrated by the electric currents. The often very large inductance of such circuits gives a storage of circuit energy that is momentarily available and may account for a number of explosive phenomena like solar flares and magnetic substorms. Also, they fail to discuss how the solar wind is connected with the magnetosphere and ionosphere by currents, which are probably the main mechanisms for energy transfer from the solar wind to these regions.

However, it is not fair to concentrate attention on what is *not* mentioned. We should instead be grateful for the very important progress that the monograph represents. It is well written and should be easily understood by graduate students. I believe that the standard of magnetospheric discussion will make a quantum jump when students who have used this as *the* standard textbook begin to influence research. Their souls will be immaculate—free of magnetic merging and reconnection and of turbulence as a panacea.

In the preface, Lyons and Williams add “... the question of whether the physical process applied to a particular problem is the dominant process, has yet to be answered.” This is a wise statement. One meets so many cases where experimentally and observationally well-established phenomena (like the “cell-wall” structure of space, the properties of electrostatic double layers, the critical velocity, and the 2:3 contraction at cosmogonic processes) have turned out to be so difficult to understand theoretically that one is in-

clined to ask whether a plasma sometimes follows laws that cannot easily be described mathematically. This means that perhaps we have to accept a basically semi-empirical approach to cosmic plasma physics, and that could very well be correct. As an analogy, quantum mechanics accounts satisfactorily for the behavior of a hydrogen atom, but the behavior of a chemical compound of one oxygen and two hydrogen atoms is already too complicated to be accounted for directly by quantum mechanics. A look at the thousand different forms of snowflakes does not encourage anyone to derive their properties directly from elementary laws. If we really find that a plasma is so complicated, we have to do as the chemists do: develop semi-empirical laws on which we base our science.

This means that even if the monograph by Lyons and Williams outlines a method of understanding many of the properties of a plasma, we perhaps should question—as the authors do—whether all the properties of a plasma can be clarified in that way.

How will the authors continue their work? They remark in the introduction that “most of the Universe is filled with plasma, and the basic interactions between plasmas, electric fields and magnetic fields being revealed in the earth’s magnetosphere are present in the development of cosmological regions....” May we conclude from this that they are going to analyze all of astrophysics, including cosmology, in a similar way? If they do, it will lead to a drastic and badly needed revision of large parts of the science. If a second conference is organized, we can look forward to a bigger and better universe.

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