

SYMPOSIUM NO. 6 OF THE
INTERNATIONAL ASTRONOMICAL UNION

ELECTROMAGNETIC
PHENOMENA IN
COSMICAL PHYSICS

EDITED BY B. LEHNERT

INTERNATIONAL ASTRONOMICAL UNION
SYMPOSIUM No. 6

HELD IN STOCKHOLM, AUGUST 1956

ELECTROMAGNETIC PHENOMENA
IN COSMICAL PHYSICS

EDITED BY

B. LEHNERT

Royal Institute of Technology, Stockholm

*Printed with
financial assistance from
U.N.E.S.C.O.*



CAMBRIDGE
AT THE UNIVERSITY PRESS

1958

PUBLISHED BY
THE SYNDICS OF THE CAMBRIDGE UNIVERSITY PRESS

Bentley House, 200 Euston Road, London, N.W. 1
American Branch: 32 East 57th Street, New York 22, N.Y.

*Printed in Great Britain at the University Press, Cambridge
(Brooke Crutchley, University Printer)*

PREFACE

An increasing interest in electromagnetic phenomena has characterized research in cosmical physics during the last decade. This development also reflects itself in an enlargement of the space devoted to electrodynamics in some recently held meetings. Two symposia on cosmical gas dynamics, at Paris in 1949 and at Cambridge in 1953, were organized by the International Astronomical Union (I.A.U.) in co-operation with the International Union of Theoretical and Applied Mechanics (I.U.T.A.M.). The programmes of these symposia included discussions on magneto-hydrodynamics, but the first meeting to be concentrated entirely on this subject was held at The Royal Society in London on the initiative of Sir Edward Bullard.

This forms the background of a subsequent symposium 'Electromagnetic Phenomena in Cosmical Physics' which was organized by the International Astronomical Union. It was held on 27-8 and 30-1 August 1956 at the Royal Institute of Technology in Stockholm, and on 29 August at the Stockholm Observatory in Saltsjöbaden. Financial support was given by I.A.U. (\$3000), I.U.P.A.P. (Union of Pure and Applied Physics; \$1500) and U.G.G.I. (Union of Geodesy and Geophysics; \$750) from U.N.E.S.C.O. funds. The Swedish Government contributed 10,000 Sw. Crs. (about \$2000) and further support was given by Telefonaktiebolaget L. M. Ericsson, Stockholm.

The organizing committee consisted of H. Alfvén (Stockholm), chairman; L. Block (Stockholm) and B. Lehnert (Stockholm), secretaries; H. W. Babcock (Pasadena), L. Biermann (Göttingen) and T. G. Cowling (Leeds). Together with the invitations a preliminary programme was sent out in advance by the organizing committee. A shortened version of this programme has been published in a circular of the I.A.U. in April 1956. Some weeks before the start of the symposium summaries of more than three-quarters of the contributions were distributed among the participants.

The following persons were present at the meetings:

Australia: J. H. Piddington (Sydney).

Belgium: P. Ledoux (Liège).

Finland: J. Tuominen (Helsinki).

France: Alice Daudin (Paris), J. F. Denisse (Paris), J. Heidmann (Paris), L. Leprince-Ringuet (Paris), E. E. Schatzmann (Paris).

Germany: L. Biermann (Göttingen), A. Ehmert (Weissenau), W. Fricke (Heidelberg), A. Schlüter (Göttingen), S. Temesváry (Göttingen).

Great Britain: P. M. S. Blackett (London), R. Hanbury Brown (Jodrell Bank, Manchester), O. Buneman (Cambridge), T. G. Cowling (Leeds), J. W. Dungey (Cambridge), H. Elliot (London), A. von Engel (Oxford), V. C. A. Ferraro (London), T. Gold (Greenwich Observatory), R. Hide (Harwell), F. D. Kahn (Manchester), R. Latham (London), A. C. B. Lovell (Jodrell Bank, Manchester), F. J. Lowes (S.M.R.E., Harpur Hill), D. Mestel (Leeds), R. S. Pease (Harwell), P. H. Roberts (A.W.R.E., Aldermaston), Pamela Rothwell (London), P. A. Sweet (London), R. J. Tayler (Harwell), W. B. Thompson (Harwell), P. C. Thonemann (Harwell).

India: V. Sarabhai (Ahmedabad), D. Venkatesan (Ahmedabad; temporarily in Stockholm).

Italy: Francesca Bachelet (Roma), G. Righini (Firenze).

Japan: Y. Fujita (Tokyo).

Netherlands: H. C. van de Hulst (Leiden).

Norway: Guro Gjellestad (Bergen), E. Jensen (Oslo), H. Trefall (Bergen).

Poland: K. Serkowski (Warsaw), W. Zonn (Warsaw).

Sweden: H. Alfvén (Stockholm), E. Åström (Stockholm), L. Block (Stockholm), E. Å. Brunberg (Stockholm), A. Dattner (Stockholm), D. Eckhardt (Stockholm), Aina Elvius (Saltsjöbaden), T. Elvius (Saltsjöbaden), N. Herlofson (Stockholm), G. Larsson-Leander (Saltsjöbaden), B. Lehnert (Stockholm), B. Lindblad (Saltsjöbaden), S. Lundquist (Stockholm), E. Lyttkens (Uppsala), Y. Öhman (Saltsjöbaden), A. Reiz (Lund), A. E. Sandström (Uppsala), W. Stoffregen (Uppsala).

U.S.A.: H. W. Babcock (Pasadena, Calif.), A. Baños (Los Angeles, Calif.), W. H. Bostick (Hoboken, N.J.), G. R. Burbidge (Pasadena, Calif.), L. Davis (Pasadena, Calif.), A. Deutsch (Pasadena, Calif.), S. E. Forbush (Washington, D.C.), E. O. Hulburt (Washington, D.C.), A. Kantrowitz (Everett, Mass.), G. F. W. Mulders (U.S. Office of Naval Research, London), E. Parker (Chicago, Ill.), K. Prendergast (Yerkes Observatory, Wis.), J. A. Simpson (Chicago, Ill.), S. F. Singer (College Park, Md.), L. Spitzer (Princeton, N.J.), W. F. G. Swann (Swarthmore, Penn.).

U.S.S.R.: L. A. Artsimovich (Moscow), I. N. Golovin (Moscow), A. J. Kipper (Tartu), E. R. Mustel (Moscow), A. B. Severny (Simeis), J. P. Terletzsky (Moscow).

The discussions were confined to such questions as could be investigated by theory, experiments and observations with a reasonable hope of success. Further considerations on the purpose and formation of the symposium programme are given by H. Alfvén in the 'Opening Address' of this volume. The main subjects of the sessions as well as the titles of the presented papers are given in the table of contents.

A chairman and a secretary were elected for each session. The arrangements were as follows:

Monday, 27 August

Morning. Chairman: W. F. G. SWANN, Secretary: R. HIDE. Opening Address and Papers 1-4.

Afternoon. Chairman: J. H. PIDDINGTON; Secretary, R. HIDE. Papers 5-7.

Tuesday, 28 August

Morning. Chairman: P. M. S. BLACKETT; Secretary, B. LEHNERT. Papers 8-11.

Afternoon. Chairman, G. RIGHINI; Secretary, O. BUNEMAN. Papers 12-17.

Wednesday, 29 August

Chairman: P. LEDOUX; Secretary, E. PARKER. Papers 18-25.

Thursday, 30 August

Morning. Chairman: V. C. A. FERRARO; Secretary: A. SCHLÜTER. Papers 26-30.

Afternoon. Chairman: L. SPITZER; Secretary: E. JENSEN. Papers 31-35.

Friday, 31 August

Morning. Chairman: L. LEPRINCE-RINGUET; Secretary: R. TAYLER. Papers 36-42.

Afternoon. Chairman: A. B. SEVERNY; Secretary: J. HEIDMANN. Papers 43-46.

In addition, notes were taken, a tape-recorder was used and the comments were written down on special forms by the speakers taking part in the discussions.

On 27 August a tour was arranged around the Department of Electronics. The present work on cosmic ray intensity variations, cosmic ray orbits, electron orbits, plasma-resonance, model experiments on the

aurorae and magnetic storms and magneto-hydrodynamic experiments with mercury was shown. Further, the Stockholm Observatory in Saltsjöbaden was visited on Wednesday, 29 August. Professor B. Lindblad gave a survey of the history of the observatory, and the instruments and some observational results were demonstrated to the visitors.

On Saturday, 1 September, and Monday, 3 September, some papers on high current discharges were added to the original programme. Many of the participants were still in Stockholm and took the opportunity to listen to these reports. They are included in Part VI. Part VII contains papers connected with subjects discussed at the symposium. They were not read at the conference, partly because of lack of time, and partly because some of the authors were not able to join the meetings.

Further research in the field of cosmical electrodynamics was certainly stimulated by a great number of interesting discussions. The motion of magnetic-field lines in an electric conductor was considered in connexion with a hydromagnetic dynamo and the behaviour of a magnetic field at a neutral point. Final conclusions were not reached, but the discussions clearly showed the many changing aspects of magneto-hydrodynamics and the danger of making generalizations. The importance of pressure-balanced magnetic fields was stressed in connexion with the magneto-hydrostatic equilibrium of cosmic gas masses.

A rigorous theory on magneto-turbulence has not yet been established. This makes it somewhat difficult to assess the importance of turbulence for phenomena in solar physics, interplanetary space and cosmic radiation. There has earlier been some confusion about the electrical conductivity in a magnetic field. The difficulties now seem to have been overcome and the 'friction coefficient' between the ion and electron fluids in a fully ionized gas is accepted as a fruitful approach.

Experiments are valuable tools in magneto-hydrodynamic research, and there are even interesting experimental results which are not predicted by theory or observations, e.g. the plasmoids. Care is necessary, however, when an extrapolation is made of experimental results to cosmical physics.

In the session on solar electrodynamics interesting attempts were made to explain the solar flares as a pinch effect, as the form of a neutral point discharge or, finally, as the result of collisions between an oscillating plasma and a neutral gas. Some new aspects were presented on the origin and structure of sunspots.

The problem of magnetic variable stars is still open for discussion. The observed field variations may be due to magneto-hydrodynamic oscillations, to the motion of the star as a rigid rotator or to both effects.

Too little is still known of the physics of interplanetary space. Therefore the connexion between solar phenomena and associated terrestrial phenomena such as magnetic storms and aurorae is rather speculative, and entirely different theories can exist side by side in this field.

Finally, cosmic radiation and its time variations can be explained in many ways. One important question is how the obtained data are affected by observational methods.

The Unions express their gratitude to U.N.E.S.C.O. for the financial help to this symposium. A publication grant for this volume is gratefully acknowledged. I want to express my sincere thanks to Mrs B. Törnell for invaluable help during the symposium and for skilled assistance with the manuscripts and discussions of this volume. I am also indebted to my father Prof. E. Lehnert for valuable help with the manuscripts.

B. LEHNERT

ROYAL INSTITUTE OF TECHNOLOGY

STOCKHOLM

April 1957

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OPENING ADDRESS

BY H. ALFVÉN

Royal Institute of Technology, Stockholm

On behalf of the organizing committee and of the Royal Institute of Technology I wish you welcome to this symposium. I need not stress the importance of the subject which we are going to discuss—as participants in this symposium all of us are aware of it. You also know very well how this field has been opened by Birkeland and Störmer, by Chapman, Cowling and Ferraro, by Hale, Swann, and many others. However, it is not until the last decade that the interest in this subject has become more general. Many different research groups are active but their ideas differ very much, which gives a good reason for meeting and exchanging ideas.

The first meeting in this field was called by Professor Bullard in London last year. The present one is the second meeting, and considering the rapid development I expect that there will be many similar meetings in the near future. Moreover, our field now tends to become important even for the peaceful use of thermonuclear energy, which adds technological interest to the purely scientific interest.

Concerning the programme it is obvious that a full coverage of the title 'Electromagnetic phenomena in cosmical physics' should also have included ionosphere physics, radioastronomy, the problems concerning the origin of cosmic radiation, and perhaps also the origin of the solar system. However, these branches have been excluded from the programme for different reasons. For example, radioastronomy was discussed only a year ago in Manchester. Even so there remain three important fields for the symposium:

(1) *Fundamental magneto-hydrodynamics* including currents in gases in the presence of a magnetic field. Although the emphasis has been and still is lying on the theoretical investigations, important experimental investigations will also be reported.

(2) *Stellar magnetism* is a rapidly developing branch of astronomy, which directs the interest to the importance of electromagnetism to stellar phenomena.

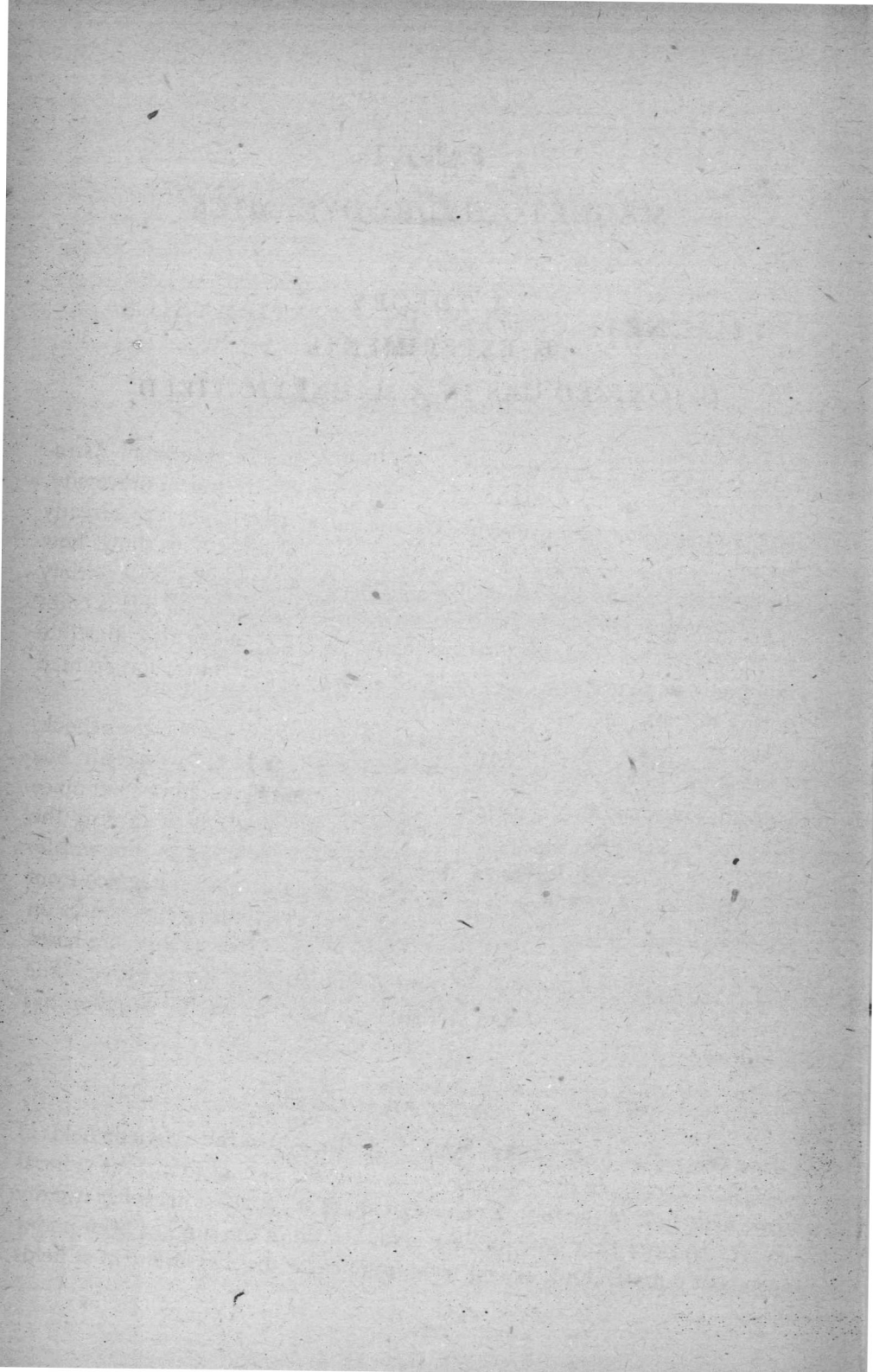
(3) *Electromagnetic phenomena within the solar system* may be an appropriate subheading including *solar electrodynamics, magnetic storms and aurorae*, and

cosmic ray intensity variations. It is an important purpose of the symposium to stimulate the fusion of these different fields into a common field of research, which at the same time gives us an example of the application of fundamental magneto-hydrodynamics to astrophysics.

The symposium will also include a visit to the Stockholm Observatory, Saltsjöbaden, and a demonstration of laboratory experiments with cosmical applications at the Royal Institute of Technology.

PART I
MAGNETO-HYDRODYNAMICS

- A. THEORY**
B. EXPERIMENTS
C. IONIZED GAS IN A MAGNETIC FIELD



A. THEORY

PAPER I

MAGNETIC FIELDS IN ASTROPHYSICS

H. C. VAN DE HULST

University Observatory, Leiden, Netherlands

This symposium is held under the auspices of the International Astronomical Union at the department of electronics of a technical university. This combination of astronomy and technical electronics has already become so familiar, that it hardly strikes us as peculiar. This shows how strongly the case for electric and magnetic phenomena in a wide variety of astrophysical problems has been proven. However, all of this is comparatively recent history. One glance at an older epoch may illustrate this point and, perhaps, may help us to take fewer things for granted during our discussions.

Just fifty years ago, in 1906, Agnes Clerke^[1] wrote a modern textbook, *Problems in Astrophysics*. In it the term magnetic field occurs only in one context. She devotes three pages to a problem that has an important place also in this symposium, namely the role of the sunspots in causing the terrestrial magnetic storms. Her discussion is concluded by the words: 'The machinery by which electromagnetic impulses are propagated from the sun to the earth, completely evades scrutiny. Sundry conjectures on the subject have been hazarded, but none of them rests on any sure basis. What we know about modes of communication is chiefly negative.' The discussions at this symposium will show to what extent the situation has improved.

I. SOLAR PHENOMENA

Two years after Miss Clerke's book, Hale discovered the magnetic fields of sunspots and again five years later, he believed he had found the general magnetic field of the sun. Knowledge about the sunspot fields has rapidly increased since that time, but the general field of the sun has been under constant debate. Only recent techniques allow the measurement of fields