GEOMAGNETISM

VOLUME 2

Edited by J. A. JACOBS

Geomagnetism

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1987

ACADEMIC PRESS
Harcourt Brace Jovanovich, Publishers
London Orlando San Diego New York Austin
Boston Sydney Tokyo Toronto

ACADEMIC PRESS LIMITED
24/28 Oval Road, London NW1 7DX

United States Edition Published by
ACADEMIC PRESS INC.
Orlando, Florida 32887

British Library Cataloguing in Publication Data

Jacobs, J.A.
Geomagnetism.
Vol. 2
1. Magnetism, Terrestrial
I. Title
538'.7 QC815.2

ISBN 0-12-378672-X

Typeset and printed in Northern Ireland by
The Universities Press (Belfast) Ltd

Geomagnetism

Volume 2

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General Preface

In their classic two-volume work on geomagnetism, Chapman and Bartels (1940) say in their Preface: 'in the thousand pages of this book we have tried to collect and set in order the main facts and results of geomagnetism, based on perhaps a hundred thousand pages of printed matter (observations and discussions).' Little could they have realized the incredible growth of the subject since then. Twenty-seven years later, Matsushita and Campbell (1967) edited a two-volume work on the physics of geomagnetism. In their Preface they write: 'The typical doubling period for the accumulation of scientific knowledge during the last two centuries is about 15 years. Yet, in the newborn fields related to the upper atmosphere and space environment, the last 20 years have seen an even more phenomenal growth.'

The phenomenal growth rate has been maintained—and even accelerated over the last 20 years—and this latest attempt to summarize our knowledge of geomagnetism has resulted in four volumes.

Chapman and Bartels could between them write such a treatise. Such a task was impossible by the time Matsushita and Campbell attempted to bring the subject up to date. The task is even more impossible today. Like Matsushita and Campbell, I have had to call on experts to review their own speciality. This has led inevitably to some overlapping and some omissions, but it is hoped that the separate chapters have been combined into a coherent account of our present knowledge of geomagnetism and aeronomy. Many problems remain unsolved, and for some there is no concensus of opinion. In the latter case the views are those of the author.

Several systems of units in electromagnetism have been employed. The system most often used in geomagnetism in the past, the electromagnetic system of units (emu), is based on CGS fundamental units and adopts the permeability of free space as $\mu_0 = 4\pi$, a dimensionless number. Since the 1950s there has been a tendency for engineering and physical sciences to adopt a system based on MKS fundamental units, called the Système International (SI). At the International Association of Geomagnetism and Aeronomy (IAGA) Scientific Assembly held in Kyoto in 1973, it was agreed to adopt the SI system of units. In this system μ_0 has the value $4\pi \times 10^{-7}\,\mathrm{H\,m^{-1}}$ (or $\mathrm{kg\,m\,A^{-2}\,s^{-2}}$). Since much of the literature in geomagnetism uses the emu system, the following Table gives SI and CGS units for some common magnetic terms together with conversion factors.

Further problems arise in the conversion of SI and CGS units because there are two equations commonly used relating the magnetic induction $\boldsymbol{B}$, magnetic field strength $\boldsymbol{H}$ and magnetization $\boldsymbol{M}$. The Kyoto Assembly also adopted the relation

$$\boldsymbol{B} = \mu_0(\boldsymbol{H} + \boldsymbol{M}).$$

Although $\boldsymbol{B}$ and $\boldsymbol{H}$ are dimensionally equal in the CGS system, it was customary to express $\boldsymbol{H}$ in oersted and $\boldsymbol{B}$ in gauss. The traditional unit in geomagnetism is the gamma (γ) originally defined as 10^{-5} gauss. In SI units $1\,\gamma = 10^{-9}$ tesla (T) = 1 nanotesla (nT).

References

Chapman, S. and Bartels, J. (1940). *Geomagnetism.* Clarendon Press, Oxford.

Matsushita, S. and Campbell, W. H. (Eds) (1967). *Physics of Geomagnetic Phenomena.* Academic Press, New York.

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Magnetic term	Symbol	SI unit	CGS Unit	Conversion factor
Magnetic induction	$\boldsymbol{B}$	tesla (T) = henry (H) A m^{-2} = kg A^{-1} s^{-2}	gauss	1 T = 10^4 gauss
Magnetic field strength	$\boldsymbol{H}$	A m^{-1}	oersted (Oe)	1 A m^{-1} = $4\pi \times 10^{-3}$ Oe
Magnetization	$\boldsymbol{M}$	A m^{-1}	emu cm^{-3} (no special name)	1 A m^{-1} = 10^{-3} emu cm^{-3}
Magnetic dipole moment	$\boldsymbol{m}$	A m^2	emu	1 A m^2 = 10^3 emu
Magnetic flux	Φ	weber (Wb) = H A = kg m^2 A^{-1} s^{-2}	maxwell	1 Wb = 10^8 maxwell
Permeability of free space	μ_0	H m^{-1} = kg m A^{-2} s^{-2}	1	$4\pi \times 10^{-7}$ H m^{-1} = 1 cgs
Conductivity	σ	siemen (S) m^{-1} = mho m^{-1} = kg^{-1} m^{-3} A^2 s^3	emu	1 S m^{-1} = 10^{-11} emu

Preface to Volume 2

This second volume discusses the origin of the Earth's magnetic field and that of the Moon and other planets. For this it is necessary to have a thorough understanding of magnetohydrodynamics. In the first chapter D. Gubbins and P. H. Roberts lay the groundwork by giving a concise account of the mathematics involved, which is essential for the next two chapters. They begin by considering the basic equations of hydrodynamics and thermodynamics, before adding the additional complication of a magnetic field. Density stratification in the Earth's core (due to compositional and temperature gradients) is discussed, together with its role in the convection of rotating fluids. The importance of the Proudman–Taylor theorem for the Earth's core, Rossby waves and boundary layers are all discussed before the effect of a magnetic field on a rotating system is considered. For a perfect fluid, Alfvén's frozen-flux theorem and its application to the secular variation, Alfvén waves, torsional waves and magnetic–Archimedian–Coriolis (MAC) waves are fully described. The role of diffusion in promoting instabilities and its effect on the secular variation is discussed, as is the question of electromagnetic screening of the core by the mantle and electromagnetic coupling of the core and mantle.

In the next two chapters, Gubbins and Roberts discuss the origin of the Earth's magnetic field—essentially dynamo theory. Chapter 2 discusses the kinematic effects and Chapter 3 the dynamics. Anti-dynamo theories are reviewed—especially Cowling's theorem, which is often misinterpreted. Various energy sources are considered (thermal, gravitational, rotation) and their merits assessed. Constraints and bounds for dynamo action are discussed (including the magnitude of the magnetic Reynolds number R_m and the radial component of the fluid motion). Mean-field electrodynamics and the role of helicity in dynamo action are reviewed. The α-effect and α^2- and $\alpha\omega$-dynamos are discussed in detail. The effect of the magnetic field $\boldsymbol{B}$ on α and on ω is considered, and a number of dynamo models (both strong-field and weak-field) are described in some detail (including Busse's model, Braginsky's $\alpha\omega$-model and model Z, the Childress–Soward model and Glatzmaier's model).

The remaining chapters of this volume are devoted to the magnetic field of the Moon, the other planets and meteorites. They include the latest analyses of satellite data and, since no more space probes are planned in the near future, these chapters give the state of the art at the moment and most probably for many years to come.

M. Fuller and S. M. Cisowski begin by discussing the identification and characterization of magnetic phases in lunar samples. The palaeomagnetic record of the Apollo samples is reviewed in great detail including their demagnetization characteristics and palaeointensities. Present lunar magnetic fields are also discussed. The results are critically assessed and the origin of lunar magnetism explored.

C. T. Russell then discusses planetary magnetism, dealing in turn with Mercury, Venus, Mars, Jupiter, Saturn and Uranus. The observations are reviewed and their interpretations critically assessed. The existence or otherwise of an intrinsic magnetic field is one of the few pieces of evidence we have on the constitution of the interiors of the planets, and has played a key role in our ideas of their evolution.

This volume ends with a chapter on the magnetism of meteorites by S. M. Cisowski. After defining the magnetic classification and magnetic properties of meteorites, Cisowski discusses the palaeointensity measurements of their field. Interpretation of the results is dependent on assumptions about the nature of their parent bodies, since the source of the magnetic field could be either internal (e.g. a liquid core dynamo) or external (e.g. solar wind). Evidence for the existence of substantial magnetic fields of external origin would provide valuable clues on the early evolution of the solar system.

J. A. Jacobs

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