Magnetic Oxides

Gerald F. Dionne

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Springer

Gerald F. Dionne
Massachusetts Institute of Technology
244 Wood Street
Lexington, MA 02420
dionne@ll.mit.edu

ISBN 978-1-4419-0053-1 e-ISBN 978-1-4419-0054-8
DOI 10.1007/978-1-4419-0054-8
Springer New York Dordrecht Heidelberg London

Library of Congress Control Number: 2009935694

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

The author dedicates this book to

Rev. Hugh McPhee, S.J.,
former Dean of Science at Loyola College
in Montreal,

who once advised a liberal arts student
that science could offer a clearer window
on the world.

Preface

The inspirations for this book probably began in 1961 when I left a promising career as a semiconductor device engineer in the Rte 128 cauldron of the Boston area to pursue a new challenge at the McGill University Eaton Electronics Research Laboratory. Three years later I wrote a Ph.D. thesis on paramagnetic resonance and 3 years after I was adding to that experience as a Staff Member with MIT Lincoln Laboratory, where the scope of my obligations gradually broadened from microwave magnetic resonance to the physics and chemistry of ferrites and related magnetic oxide systems. At the time of this writing, I continue there as a resident consultant and also as a research affiliate with the MIT Department of Materials Science and Engineering.

Magnetic resonance has played a vital role in the study of magnetism in oxides and other insulating compounds that began during World War II and flourished globally for a quarter century. During this halcyon period, texts on magnetism became abundant as many of the pioneers took pen in hand to leave a treasure of elegantly presented reference literature as the 1960s drew to a close. By the mid-1970s, the once-fledgling field of semiconductor electronics that I had abandoned was overwhelming almost all competing technologies, including those with a magnetic component. For the better part of the two decades between the end of the Vietnam war and the discoveries of high-temperature superconductivity and giant magnetoresistance in transition-metal oxides in the early 1990s, fundamental investigations of magnetic compounds were nearly dormant.

The content and organization of this volume are intended to serve two purposes: (1) bridging of the intellectual gap left by the 20 years of reduced inquiry into magnetic phenomena, and (2) restoration of the molecular approach to the study of magnetic insulators that function more by local rather than the collective electron interactions that are more characteristic of metals and semiconductors.

The level of discussion presumes the reader to have some familiarity with atomic physics and basic quantum mechanics. Chapter 1 is an abbreviated introduction to magnetism. The discussion begins with a reminder of some fundamental definitions and selected subjects that can be found in most standard textbooks. However, two topics are treated in greater depth. A generic description of the quantum origins of magnetic exchange introduces the antisymmetry requirements of the hybrid eigenstates that determine the stabilization of parallel (metal) or antiparallel (insulator) spin alignment. This general theory is intended to support the later discussion of superexchange that is approached with a model that is more specific to magnetic oxides. An introduction to magnetic resonance and relaxation derived from classical Larmor precession serves a similar purpose for the examination of the broad subject of electromagnetism in ferrites. The physics and chemistry of magnetism in oxide compounds is covered in Chaps. 2, 3, and 4 in terms of localized ion and molecular-orbital models of molecular bonding. Chapter 5 addresses the secondary magnetic phenomena of anisotropy and magnetostriction from the standpoint of local orbital interactions with crystal fields and spin–orbit coupling that produces self-induced magnetoelastic effects. Traditional phenomenological theories are then reviewed in preparation for the examination of electromagnetic properties in Chap. 6. In Chaps. 7 and 8, magneto-optics and polarized spin transport that will be of increasing importance in the age of molecular-scale structures are described in the conceptual context of the earlier chapters.

As the preparation of this monograph draws to a close, I reflect on the journey that brought me to this point. From the frequency of their citations, the reader is certain to recognize the reliance on the seminal works of John Van Vleck, Maurice Pryce, John Goodenough, and Ernst Schlœmann, as well as the classic textbooks of Alan Morrish, Sōshin Chikazumi, Carl Ballhausen, Benjamin Lax and Kenneth Button, and many others. There were also collaborations with academia, industry, and government that are too numerous to list in any detail. However, I cannot pass up this opportunity to acknowledge the guidance of my doctoral thesis advisor Garnet Woonton and his colleague Maurice Pryce who was a most encouraging external examiner. Lincoln Laboratory's radar leaders John Allen, Carl Blake, Donald Temme, and Roger Sudbury who supported me and my vigorous colleagues Jerald Weiss, James Fitzgerald, Daniel Oates, and Russell West (of Trans-Tech, Inc.). Then there was the mentorship of John Goodenough and Benjamin Lax and the MIT campus affiliations with Mildred and Gene Dresselhaus, and Caroline Ross. Finally, I must mention the associations with Kristl Hathaway, Gary Prinz, and Stuart Wolf of the US Departments of the Navy and DARPA, and the assistance of Elaine Tham and Lauren Danahy of Springer US.

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Contents