Preface

Frustrated magnetism has become an extremely active field of research. After undergoing a revival in the 1990s in the context of applying Anderson's resonating-valence-bond (RVB) theory to high-temperature superconductors, the subject has experienced a tremendous burst of theoretical and experimental activity in the last decade. Since its first edition in 2000, the major conference in the field, "Highly Frustrated Magnetism," now takes place every 2 years and has seen very rapid growth in participant number. Broad research networks on frustration and related topics have been established recently both in Europe and in Japan.

Within the context of the European Network on Highly Frustrated Magnetism, which gathers 14 countries and is supported by the European Science Foundation (2005–2010), we made the decision to edit a book that would cover all of the important aspects of the field. The subject matter would span each of its three pillars: materials, experiment, and theory. The summer school which was held in Trieste in summer 2007 as an activity of the ESF network presented the ideal opportunity for the definitive launch of this project. The response was very positive, and the 400-page volume planned at the outset has increased in size over the intervening months due to the enthusiasm of the authors, who have produced beautiful reviews both significantly longer and broader in scope than initially foreseen.

The driving force behind the considerable current activity is the conviction, now demonstrated by numerous examples, that frustrated magnetism presents an excellent proving ground in which to discover new states and new properties of matter. For theorists, this conviction comes from the simple observation that long-range magnetic order, the standard low-temperature instability, cannot be achieved due to the proliferation of possible ground states. This is true both for classical systems, where averaging over the various ground states often leads to decaying correlations at large distances, and for quantum systems, where this proliferation translates into a very soft spectrum and diverging fluctuations.

The list of proposed alternatives to long-range order is already impressive (residual entropy, algebraic or dipolar correlations, gapped or gapless spin liquids, spin nematics, . . .), and one may anticipate further increases over the coming years. A good example is the role played by frustration in many multiferroic systems. While the proposals are theoretical, at the root of many of these developments have been materials scientists. They have invented new families of compounds, rediscovered some existing minerals, found synthesis routes to produce them in a form purer than the natural species, and even discovered some variants of these. Artificial frustrated lattices have begun to pave the way towards further new challenges. However, despite all of these efforts, most of the possible states of matter predicted by theory remain largely unexplored at the experimental level, and the ultra-clean realizations of materials required to probe critical behavior are still lacking. There is no doubt that materials science has a leading role to play in the future of frustrated magnetism.

Experimentally, the absence of a phase transition at a temperature of the same order as the typical coupling constant signals the possibility of unconventional low-temperature physics. This is often quantified by the ratio Θ_{CW}/T_c, sometimes called the Ramirez frustration ratio, where Θ_{CW} is the Curie–Weiss temperature and T_c the critical temperature (if any). Strong frustration always produces a large ratio. Values around 50 are not uncommon, and there is no upper limit: in a number of systems, no phase transition to any type of order has been detected to date.

The concept of frustration is now ubiquitous in physics. In the context of magnetism, the name first appeared for spin glasses to describe the difficulty experienced by these systems in reaching their true ground state when both disorder and frustration act together. While disorder certainly plays a role in the properties of the materials to be discussed in this volume, the main focus is on the intrinsic effects of "geometrical" frustration, the general term for the competition between interaction pathways which arises in clean and periodic, but frustrated, systems.

Frustration and one-dimensionality share many common features: they both lead to diverging fluctuations, to exotic excitations, and to reduced critical temperatures due to small additional interactions. However, in frustrated systems, the presence of several competing states leads to a very large number of low-lying excitations, or more generally to a redistribution of spectral weight into narrow bands. This can be manifest as an anomalously large specific heat at low temperatures (and even as a residual entropy in examples such as spin ice), or as narrow, compressible phases between incompressible magnetization plateaus.

The field of frustrated magnetism is vast, and dichotomies have emerged naturally over the years: classical vs. quantum, 2D vs. 3D, rare-earth vs. transition-metal ions, corner-sharing vs. edge-sharing lattices, Ising vs. Heisenberg interactions, etc. It would be dangerous to neglect these differences, because this is a field where details matter. Indeed, small interactions are often responsible for the ultimate selection from among several candidate ground states. This is why, with the exception of a small number of more general chapters, a significant fraction of the contributions to this volume concentrate on specific aspects or materials rather than on broader principles.

The goal of this book is two-fold: the first is to provide a solid introduction to Highly Frustrated Magnetism for researchers and PhD students beginning their activities in the field; the second is to review the more advanced topics of current interest which, in some cases, remain under development. The volume is divided into six sections. The first section contains two chapters which provide a general introduction to classical and quantum frustrated magnetism. The second section reviews the primary spectroscopic approaches (neutron scattering, resonance techniques, light scattering) upon which, in large part, our current experimental understanding of frustrated magnets is based. The third section is devoted to the synthesis and crystal growth of frustrated magnets, and to experimental reviews of the leading families of compounds with frustrated geometries (triangular, kagomé, spinel, pyrochlore). The fourth section deals with physical effects characteristic of frustration, such as magnetization plateaus, the spin-Jahn–Teller transition, spin ice, and spin nematics. The fifth section is devoted entirely to theory, presenting the primary approaches which have been deployed in trying to cope with the extremely difficult problem raised by the interplay between quantum fluctuations and frustration. Finally, the last section addresses the effects of frustration in systems with further degrees of freedom, such as mobile carriers or orbital degeneracy.

What are the leading open issues and challenges in the field? Each reader will probably have her or his own priority list among the outstanding problems to be found in this volume. The experimental realization of an RVB spin liquid and the solution of the Heisenberg model on the kagomé or on the pyrochlore lattice are long-standing ones. We hope that this book may serve both as a reference and as a springboard which can contribute to the solution of these fascinating problems.

We would like to express our sincere thanks to Bruce Normand, who proof-read the chapters written by non-native speakers of English and, in the course of this ungrateful task, also provided many insightful comments and suggestions.

In conclusion, we would like to thank the International Center for Theoretical Physics in Trieste for hosting the 2007 Summer School, as well as for supporting part of its costs, and the European Science Foundation for its constant support of the HFM network.

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August 2010

Springer

http://www.springer.com/978-3-642-10588-3

Introduction to Frustrated Magnetism
Materials, Experiments, Theory
Lacroix, C.; Mendels, P.; Mila, F. (Eds.)
2011, XXVI, 682 p., Hardcover
ISBN: 978-3-642-10588-3