Lecture Notes in Physics

Springer
Berlin
Heidelberg
New York
Hong Kong
London
Milan
Paris
Tokyo

The Editorial Policy for Edited Volumes

The series *Lecture Notes in Physics* (LNP), founded in 1969, reports new developments in physics research and teaching - quickly, informally but with a high degree of quality. Manuscripts to be considered for publication are topical volumes consisting of a limited number of contributions, carefully edited and closely related to each other. Each contribution should contain at least partly original and previously unpublished material, be written in a clear, pedagogical style and aimed at a broader readership, especially graduate students and nonspecialist researchers wishing to familiarize themselves with the topic concerned. For this reason, traditional proceedings cannot be considered for this series though volumes to appear in this series are often based on material presented at conferences, workshops and schools.

Acceptance

A project can only be accepted tentatively for publication, by both the editorial board and the publisher, following thorough examination of the material submitted. The book proposal sent to the publisher should consist at least of a preliminary table of contents outlining the structure of the book together with abstracts of all contributions to be included. Final acceptance is issued by the series editor in charge, in consultation with the publisher, only after receiving the complete manuscript. Final acceptance, possibly requiring minor corrections, usually follows the tentative acceptance unless the final manuscript differs significantly from expectations (project outline). In particular, the series editors are entitled to reject individual contributions if they do not meet the high quality standards of this series. The final manuscript must be ready to print, and should include both an informative introduction and a sufficiently detailed subject index.

Contractual Aspects

Publication in LNP is free of charge. There is no formal contract, no royalties are paid, and no bulk orders are required, although special discounts are offered in this case. The volume editors receive jointly 30 free copies for their personal use and are entitled, as are the contributing authors, to purchase Springer books at a reduced rate. The publisher secures the copyright for each volume. As a rule, no reprints of individual contributions can be supplied.

Manuscript Submission

The manuscript in its final and approved version must be submitted in ready to print form. The corresponding electronic source files are also required for the production process, in particular the online version. Technical assistance in compiling the final manuscript can be provided by the publisher‘s production editor(s), especially with regard to the publisher's own LaTeX macro package which has been specially designed for this series.

LNP Homepage (springerlink.com)

On the LNP homepage you will find:

– The LNP online archive. It contains the full texts (PDF) of all volumes published since 2000. Abstracts, table of contents and prefaces are accessible free of charge to everyone. Information about the availability of printed volumes can be obtained.

– The subscription information. The online archive is free of charge to all subscribers of the printed volumes.

– The editorial contacts, with respect to both scientific and technical matters.

– The author's / editor's instructions.

U. Schollwöck J. Richter D.J.J. Farnell R.F. Bishop
(Eds.)

Quantum Magnetism

Springer

Editors

Ulrich Schollwöck
RWTH Aachen
Institut für Theoretische Physik C
52056 Aachen, Germany

Johannes Richter
Otto-von-Guericke-Universität
Institut für Theoretische Physik
Postfach 4120
39016 Magdeburg, Germany

Damian J.J. Farnell
University of Liverpool
Dept. of Medicine Unit
of Ophthalmology
Daulby Street
Liverpool L69 3GA, U.K.

Raymond F. Bishop
UMIST Department of Physics
P.O. Box 88
Manchester M60 1QD, U.K.

U. Schollwöck, J. Richter, D.J.J. Farnell, R.F. Bishop (Eds.), *Quantum Magnetism*, Lect. Notes Phys. **645** (Springer, Berlin Heidelberg 2004), DOI 10.1007/b96825

Library of Congress Control Number: 2004102970

Bibliographic information published by Die Deutsche Bibliothek Die Deutsche Bibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data is available in the Internet at <http://dnb.ddb.de>

ISSN 0075-8450
ISBN 3-540-21422-4 Springer-Verlag Berlin Heidelberg New York

Springer-Verlag is a part of Springer Science+Business Media

springeronline.com

Typesetting: Camera-ready by the authors/editor
Data conversion: PTP-Berlin Protago-TeX-Production GmbH
Cover design: *design & production*, Heidelberg

Printed on acid-free paper
54/3141/ts - 5 4 3 2 1 0

Preface

Putting the quantum into magnetism might, at first sight, seem like stating the obvious; the exchange interactions leading to collective magnetic behavior are, after all, a pure quantum effect. Yet, for many phenomena in magnetism this underlying quantum nature may be safely ignored at least on the qualitative level. The investigation of magnetic systems where quantum effects play a dominant role and have to be accounted for in detail has, over the last decades, evolved to be a field of very active research. On the experimental side, major boosts have come from the discovery of high-temperature superconductivity in the mid-eighties and the increasing ability of solid state chemists to fashion magnetic systems of restricted dimensionality. While high-temperature superconductivity has raised the question of the link between the mechanism of superconductivity in the cuprates and spin fluctuations and magnetic order in one- and two-dimensional spin-1/2 antiferromagnets, the new magnetic materials have exhibited a wealth of new quantum phenomena of interest in their own. In one-dimensional systems, the universal paradigm of Luttinger liquid behavior has come to the center of interest; in all restricted geometries, the interplay of low dimension, competing interactions and strong quantum fluctuations generates, beyond the usual long range ordered states, a wealth of new states of condensed matter, such as valence bond solids, magnetic plateaux, spin liquid states or spin-Peierls states, to name but a few.

The idea for this book arose during a Hereaus seminar on "Quantum Magnetism: Microscopic Techniques For Novel States of Matter" back in 2002, where it was realized that a set of extensive tutorial reviews would address the needs of both postgraduate students and researchers alike and fill a longstanding gap in the literature.

The first three chapters set out to give an account of conceptual problems and insights related to classes of systems, namely one-dimensional (Mikeska and Kolezhuk), two-dimensional (Richter, Schulenburg and Honecker) and molecular (Schnack) magnets.

The following five chapters are intended to introduce to methods used in the field of quantum magnetism, both for independent reading as well as a backup for the first chapters: this includes time-honored spin wave analysis (Ivanov and Sen), exact diagonalization (Laflorencie and Poilblanc), quantum field theory (Cabra and Pujol), coupled cluster methods (Farnell and Bishop) and the Bethe ansatz (Klümper).

To close, a more unified point of view is presented in a theoretical chapter on quantum phase transitions (Sachdev) and an experimentally oriented contribution (Lemmens and Millet), putting the wealth of phenomena into the solid state physics context of spins, orbitals and lattice topology.

Aachen, Magdeburg, Liverpool, Manchester
March 2004

Ulrich Schollwöck
Johannes Richter
Damian Farnell
Ray Bishop

Contents

List of Contributors

Raymond F. Bishop
University of Manchester
Institute of Science and Technology (UMIST)
Department of Physics
P.O. Box 88
Manchester M60 1QD, UK
r.f.bishop@umist.ac.uk

Daniel C. Cabra
Université Louis Pasteur
Strasbourg, France
cabra@lpt1.u-strasbg.fr

Damian J.J. Farnell
University of Liverpool
University Clinical Departments
Department of Medicine
Unit of Ophthalmology
Daulby Street
Liverpool L69 3GA, UK
d.farnell@liverpool.ac.uk

Andreas Honecker
TU Braunschweig
Institut für Theoretische Physik
Mendelsohnstr. 3
38106 Braunschweig, Germany
a.honecker@tu-bs.de

Nedko B. Ivanov
Universität Augsburg
Theoretische Physik II
86135 Augsburg, Germany
Permanent address:
Bulgarian Academy of Sciences
Institute of Solid State Physics
Tsarigradsko chausse 72
1784 Sofia, Bulgaria
ivanov@physik.uni-augsburg.de

Andreas Klümper
Universität Wuppertal
Theoretische Physik
Gauß-Str. 20
42097 Wuppertal, Germany
kluemper
@physik.uni-wuppertal.de

Alexei K. Kolezhuk
Institute of Magnetism,
National Academy of Sciences and Ministry of Education of Ukraine,
Vernadskii prosp. 36(B),
Kiev 03142, Ukraine
kolezhuk@itp.uni-hannover.de

Nicolas Laflorencie
Université Paul Sabatier
Laboratoire de Physique Théorique
CNRS-UMR5152
31062 Toulouse, France
nicolas.laflorencie
@irsamc.ups-tlse.fr

Peter Lemmens
Max Planck Institute
for Solid State Research
Heisenbergstrasse 1
70569 Stuttgart, Germany
p.lemmens@fkf.mpg.de

Hans-Jürgen Mikeska
Universität Hannover
Institut für Theoretische Physik
Appelstaße 2
30167 Hannover, Germany
mikeska@itp.uni-hannover.de

Patrice Millet
Centre d'Élaboration des Matériaux
et d'Études Structurales,
CNRS
BP 4347
31055 Toulouse Cedex 4, France
millet@cemes.fr

Didier Poilblanc
Université Paul Sabatier
Laboratoire de Physique Théorique
CNRS-UMR5152
31062 Toulouse, France
didier.poilblanc
@irsamc.ups-tlse.fr

Pierre Pujol
École Normale Supérieure
Lyon, France
ppujol@ens-lyon.fr

Johannes Richter
Otto-von-Guericke-Universität
Institut für Theoretische Physik
P.O.Box 4120
39016 Magdeburg, Germany
johannes.richter
@physik.uni.magdeburg.de

Subir Sachdev
Yale University
Department of Physics
P.O. Box 208120
New Haven CT 06520-8120, USA.
subir.sachdev@yale.edu

Jürgen Schnack
Universität Osnabrück
Abteilung Physik
49069 Osnabrück, Germany
jschnack@uos.de

Jörg Schulenburg
Otto-von-Guericke-Universität
Universitätsrechenzentrum
P.O.Box 4120
39016 Magdeburg, Germany
joerg.schulenburg
@urz.uni-magdeburg.de

Diptiman Sen
Indian Institute of Science
Center for Theoretical Studies
Bangalore 560012, India
diptiman@cts.iisc.ernet.in