

# Contents

<b>Contributors</b> .....	<b>xiii</b>
<b>Preface</b> .....	<b>xv</b>
<b>1: Molecular Nanomagnets Based on <i>f</i>-Elements</b> .....	<b>1</b>
Eufemio Moreno-Pineda, Lydia E. Nodaraki, Floriana Tuna	
1.1 Introduction.....	1
1.2 General Aspects of <i>4f</i> and <i>5f</i> Ions.....	3
1.2.1 Electronic Structure of Lanthanides.....	3
1.2.2 Electronic Structure of Actinides.....	4
1.3 Slow Magnetic Relaxation in <i>f</i> -Element Nanomagnets.....	6
1.3.1 Effect of Single-Ion Anisotropy.....	6
1.3.2 Effect of Local Geometry.....	7
1.3.3 Symmetry Aspects.....	9
1.3.4 Magnetic Relaxation Mechanisms .....	11
1.4 Experimental Methods.....	13
1.4.1 DC Magnetometry .....	14
1.4.2 AC Magnetometry .....	15
1.4.3 $\mu$ -SQUID Arrays.....	17
1.5 Slow-Relaxing Systems.....	18
1.5.1 <i>f</i> -Elements Single-Ion Magnets ( <i>f</i> -SIMs).....	18
1.5.2 <i>f</i> -Elements Single-Molecule Magnets ( <i>f</i> -SMMs).....	31
1.5.3 <i>f</i> -Elements Single-Chain Magnets ( <i>f</i> -SCM).....	39
1.6 Conclusions and Perspectives .....	44
References.....	45
<b>2: Metallocrown Complexes Reaching the Nanosize Regime</b> .....	<b>51</b>
Angeliki A. Athanasopoulou, Christoph Gamer, Lara Völker, Eva Rentschler	
2.1 Introduction.....	51
2.2 Metallocrown Complexes .....	52
2.2.1 Ligands.....	52
2.2.2 Metal Ion Variation— <i>3d</i> to <i>4f</i> Compounds .....	54
2.2.3 Luminescent Metallocrown Complexes .....	61
2.2.4 Metallocrown Complexes as Single-Molecule Magnets (SMMs).....	70
2.3 Moving from 0 to 3D Structures.....	80
2.3.1 Metallocrown Linkage.....	80



2.3.2 Multidimensionality of Extended Networks .....	85
2.4 Conclusion and Perspectives .....	91
References.....	92
Further Reading .....	96
<b>3: Multifunctional Properties of <math>\gamma</math>-Fe<sub>2</sub>O<sub>3</sub> Nanoparticles Encapsulated Into Liquid-Crystalline Poly(propylene imine) Dendrimer.....</b>	<b>97</b>
<b>Natalia Domracheva</b>	
3.1 Introduction.....	97
3.2 Presentation of the Iron-Dendrimeric Nanocomposite and Identification of Its Liquid-Crystalline Properties.....	99
3.3 Characterization of $\gamma$ -Fe <sub>2</sub> O <sub>3</sub> NPs by Electron Magnetic Resonance .....	101
3.4 Mössbauer Spectroscopy Study.....	106
3.5 Optical Properties and the Band Gap Width of $\gamma$ -Fe <sub>2</sub> O <sub>3</sub> NPs.....	109
3.6 Photoinduced Superparamagnetic Effect in $\gamma$ -Fe <sub>2</sub> O <sub>3</sub> NPs: EPR Detection .....	113
3.7 EMR Searching of Quantum Behavior of Superparamagnetic $\gamma$ -Fe <sub>2</sub> O <sub>3</sub> Nanoparticles in Dendrimeric Nanocomposite .....	116
3.8 Conclusion .....	120
References.....	121
<b>4: Magnetic Disorder in Nanostructured Materials .....</b>	<b>127</b>
<b>Giuseppe Muscas, Nader Yaacoub, Davide Peddis</b>	
4.1 Introduction.....	127
4.2 Magnetism in Nanostructures: An Overview .....	128
4.2.1 Magnetic Anisotropy at the Nanoscale .....	129
4.2.2 Superparamagnetism.....	132
4.2.3 Magnetic Interactions at the Nanoscale: Supermagnetism.....	134
4.3 Magnetic Disorder at the Nanoscale .....	136
4.3.1 Noncollinear Spin Structure in Nanostructured Spinel Ferrites .....	137
4.3.2 Experimental Investigation of Magnetic Disorder: Mössbauer Spectrometry .....	139
4.4 Magnetic Properties of Spinel Ferrites Nanoparticles: Influence of the Magnetic Disorder .....	143
4.4.1 Magnetic Properties of CoFe <sub>2</sub> O <sub>4</sub> Nanoparticles: Effect of the Magnetic Structure.....	143
4.4.2 Magnetic Properties of Spinel Ferrite Nanoparticles: Effect of the Chemical Composition.....	149
4.4.3 Surface and Interface Magnetism: The Role of Molecular Coating .....	152
4.5 Conclusions and Perspectives .....	156
References.....	158
<b>5: Self-Assembly of Magnetic Iron Oxide Nanoparticles Into Cuboidal Superstructures .....</b>	<b>165</b>
<b>Sabine Rosenfeldt, Stephan Förster, Thomas Friedrich, Ingo Rehberg, Birgit Weber</b>	
5.1 Motivation.....	165



5.1.1	Properties of Magnetic Iron Oxide Nanoparticles .....	165
5.1.2	Applications of Magnetic Iron Oxide Nanoparticles .....	166
5.2	Synthesis and Properties of Nanoparticles .....	166
5.2.1	Synthesis of Spherical and Cubic Iron Oxide Nanoparticles .....	167
5.2.2	Magnetic Properties of the Nanoparticles .....	171
5.3	Self-Assembly Into Superstructures .....	173
5.3.1	Crystallization of Cuboids .....	174
5.3.2	Influence of the Magnetic Field .....	177
5.4	Conclusion .....	187
	Acknowledgments .....	188
	References .....	188
<b>6:</b>	<b><i>Nanomaterials for Magnetoplasmonics</i></b> .....	<b>191</b>
	<b>Francesco Pineider, Claudio Sangregorio</b>	
6.1	Introduction .....	191
6.2	Experimental Methods for the Study of Magnetoplasmonics and Related Effects .....	193
6.2.1	Polarization States of Light .....	193
6.2.2	Magneto-Optical Techniques .....	195
6.3	Plasmonics and Magnetoplasmonics .....	197
6.3.1	Plasmonics and Active Plasmonics .....	197
6.3.2	Magnetoplasmonics .....	201
6.4	Magnetoplasmonics in Single-Component Nanostructures .....	202
6.4.1	Nonmagnetic Metals .....	202
6.4.2	Ferromagnetic Metals .....	208
6.5	Hybrid Magnetoplasmonic Nanostructures .....	210
6.5.1	Plasmonic Metals/Magnetic Metals .....	210
6.5.2	Plasmonic Metals/Magnetic Oxides .....	214
6.5.3	Plasmonic Metals/Magnetic Molecules .....	215
6.6	Conclusion .....	217
	Acknowledgment .....	217
	References .....	217
<b>7:</b>	<b><i>Highly Responsive Magnetoactive Elastomers</i></b> .....	<b>221</b>
	<b>Mikhail Shamonin, Elena Yu. Kramarenko</b>	
7.1	Introduction .....	221
7.2	Constitutive Materials .....	222
7.2.1	Polymer Matrix .....	222
7.2.2	Filler Particles .....	223
7.2.3	Filler-Filler Interactions in Magnetic Fields .....	225
7.3	Mechanical Properties in Homogeneous Magnetic Fields .....	226
7.3.1	Magnetostriction .....	226
7.3.2	Magnetorheological Effect .....	228
7.3.3	Filler-Matrix Interactions in Magnetic Fields: Payne Effect .....	232
7.3.4	Hysteretic Behavior .....	234



7.3.5 Magnetodeformation in Inhomogeneous Fields.....	235
7.4 Electromagnetic and Acoustic Properties .....	237
7.5 Prospects of Research and Development .....	238
7.6 Conclusion .....	239
Acknowledgments .....	240
References.....	240
<b>8: Neel Effect: Exploiting the Nonlinear Behavior of Superparamagnetic Nanoparticles for Applications in Life Sciences up to Electrical Engineering .....</b>	
<b>247</b>	
<b>Luc Lenglet, Laurence Motte</b>	
8.1 Louis Néel, Superparamagnetism, and Neel Effect <sup>®</sup> .....	247
8.2 Neel Effect for Particle Sensing.....	249
8.2.1 Magnetic Immunoassays .....	249
8.2.2 Magnetic Particle Imaging .....	254
8.2.3 Real-Time Monitoring.....	255
8.2.4 Magnetic Colorization.....	257
8.3 Neel Effect for Magnetic Field Sensing .....	260
8.3.1 Current Sensors.....	260
8.3.2 Position Sensors.....	262
References.....	262
<b>9: Ferrimagnetic Heterostructures for Applications in Magnetic Recording.....</b>	
<b>267</b>	
<b>Florin Radu, Jaime Sánchez-Barriga</b>	
9.1 Magnetic Recording: Fundamentals and Perspectives .....	267
9.1.1 Perpendicular Magnetic Recording and Superparamagnetism.....	269
9.1.2 Future Areal Density Progress and Emergent Technologies.....	269
9.1.3 Heat-Assisted Magnetic Recording.....	270
9.1.4 Heat-Assisted Magnetic Recording on Bit-Patterned Media .....	271
9.1.5 Spin-Valve Systems for Magnetic Read Heads.....	273
9.1.6 Tunneling Magnetoresistance.....	276
9.1.7 Spin-Transfer Torque Effect .....	278
9.1.8 Spin Hall and Rashba-Edelstein Effects .....	280
9.1.9 All-Optical Switching and Topological Skyrmions.....	281
9.2 Ferrimagnetism .....	283
9.3 Selected Examples of Ferrimagnetic Thin Films .....	287
9.3.1 Ferrimagnetic Spin Valves .....	295
9.4 Ferrimagnetic Nanostructures for Magnetic Memory Bits.....	297
9.4.1 Magnetic Properties of FeTb Nanodots .....	303
9.4.2 DyCo <sub>5</sub> Antidots for Heat-Assisted Magnetic Recording.....	306
9.4.3 Laser-Induced Switching of FeGdCo Nanostructures .....	311
9.5 Conclusion and Outlook.....	314
References.....	315



<b>10: Nanomagnetic-Supported Catalysts .....</b>	<b>333</b>
<b>Vincent Terrasson, Erwann Guénin</b>	
10.1 Introduction.....	333
10.2 Synthesis and Property of Magnetic Nanoparticles.....	334
10.3 Preparation of NanoMagnetic-Supported Catalysts.....	336
10.3.1 Uncoated Nanoparticles.....	336
10.3.2 Nanoparticle Coating.....	337
10.4 Different Types of Catalysts Immobilized Onto Nanomagnetic Support.....	341
10.4.1 Immobilization of Enzymes .....	341
10.4.2 Immobilization of Organocatalysts .....	343
10.4.3 Immobilization of Organometallic Catalysts or Metal Nanoparticles .....	344
10.5 Application of Magnetic Nanocatalysts .....	345
10.5.1 Reduction Reactions .....	345
10.5.2 Oxidation Reactions .....	347
10.5.3 C—C Bond Formation .....	349
10.5.4 C-Heteroatom Bond Formation.....	352
10.5.5 Cycloaddition Reactions.....	353
10.5.6 C—H Activation.....	355
10.5.7 Hydrolysis .....	355
10.5.8 Kinetic Resolution by Esterification .....	355
10.6 Limitations and Outlooks .....	356
Acknowledgments .....	357
References.....	358
<b>11: Spin and Charge Tunneling Transport in Magnetic Tunnel Junctions With Embedded Nanoparticles .....</b>	<b>373</b>
<b>Artur Useinov, Chih-Huang Lai, Niazbeck Kh. Useinov, Lenar R. Tagirov</b>	
11.1 Introduction.....	373
11.2 Giant Magnetoresistance in Ferromagnetic Heteronanocontacts .....	375
11.3 Tunnel Magnetoresistance in Single- and Double-Barrier MTJ .....	380
11.4 Spin-Transfer Torque, Size Distribution, and Temperature-Related Effects in MTJs With Embedded Nanoparticles .....	387
11.5 Conclusions.....	395
Acknowledgments .....	397
References.....	397
Further Reading .....	400
<b>12: An Overview of Spin Crossover Nanoparticles.....</b>	<b>401</b>
<b>David J. Harding</b>	
12.1 Introduction to Spin Crossover .....	401
12.2 Nanoparticles and Nanocrystals .....	403
12.2.1 Triazole Systems.....	403
12.2.2 Hofmann Systems.....	405
12.2.3 Molecular Systems .....	406



12.3 Spin Crossover Nanocomposites.....	409
12.3.1 Silica Systems.....	409
12.3.2 Au Systems.....	411
12.3.3 Polymer Systems.....	412
12.3.4 Cellulose Systems.....	412
12.3.5 Graphene Systems.....	414
12.4 Spin Crossover Thin Films.....	415
12.4.1 Au, Cu, and Silica.....	415
12.4.2 Polymers.....	417
12.5 SCO Devices.....	417
12.5.1 Single Molecule Devices.....	417
12.5.2 Nanoparticle Systems.....	419
12.6 Conclusions and Future Prospects.....	422
Acknowledgments.....	422
References.....	423
<b>13: Magnetic Metal-Nonstoichiometric Oxide Nanocomposites: Structure, Transport, and Memristive Properties.....</b>	<b>427</b>
Vladimir V. Rylkov, Vyacheslav A. Demin, Andrey V. Emelyanov, Alexander V. Sitnikov, Yurii E. Kalinin, Victor V. Tugushev, Alexander B. Granovsky	
13.1 Introduction.....	427
13.2 Samples and Investigation Methods.....	428
13.2.1 Samples Preparation.....	428
13.2.2 Methods of Investigation and Technique.....	432
13.3 Structural Characterization.....	432
13.4 Temperature Dependence of Conductivity.....	435
13.5 Anomalous Hall Effect and Magnetization.....	437
13.5.1 Background and Motivation.....	437
13.5.2 Scaling Behavior of AHE and Peculiarities of Magnetization.....	439
13.5.3 Nature of Paramagnetic Centers.....	447
13.5.4 Qualitative Model of the AHE Behavior.....	448
13.5.5 Manifestation of Superferromagnetic Ordering.....	452
13.6 Memristive Properties.....	453
13.6.1 Introduction to Memristive Properties of Oxides.....	453
13.6.2 Resistive Switching Effects in Nanocomposites.....	455
13.6.3 Qualitative Model of the Resistive Switching Mechanism.....	457
13.7 Concluding Remarks.....	460
Acknowledgments.....	462
References.....	462
<b>Index.....</b>	<b>465</b>