

Contents

List of Contributors *xvii*

Preface *xxiii*

Part One Fundamentals *1*

- 1 Overview of Magnetic Nanomaterials** *3*
Ziyu Yang, Shuang Qiao, Shouheng Sun, and Yanglong Hou
 - 1.1 Introduction *3*
 - 1.1.1 Typical Magnetic Nanomaterials *4*
 - 1.1.1.1 Magnetic Nanomaterials of Metal (Fe, Co, and Ni) *4*
 - 1.1.1.2 Magnetic Nanomaterials of MN Alloys (M = Fe, Co, and Ni, N = Noble Metal) *7*
 - 1.1.1.3 Magnetic Nanomaterials of M_1M_2 Alloys ($M_1, M_2 = \text{Fe, Co, and Ni}$) *9*
 - 1.1.1.4 Magnetic Nanomaterials of Carbides and Nitrides M–C/N (M = Fe, Co, and Ni) *10*
 - 1.1.1.5 Magnetic Nanomaterials of Metal Oxides *12*
 - 1.1.1.6 Rare Earth-Based Permanent Magnets *13*
 - 1.2 Typical Characterization of Magnetic Nanomaterials *14*
 - 1.2.1 X-Ray Magnetic Circular Dichroism Spectroscopy *14*
 - 1.2.2 Lorentz Transmission Electron Microscope *15*
 - 1.2.3 Mössbauer Spectroscopy *18*
 - 1.2.4 Magnetic Extended X-Ray Absorption Fine Structure *18*
 - 1.2.5 Magnetic Force Microscopy *19*
 - 1.2.6 Magnetic Analysis *21*
 - 1.3 Conclusions *22*
 - References *22*
 - 2 Magnetism of Nanomaterials** *29*
Ralph Skomski, Balamurugan Balasubramanian, and David J. Sellmyer
 - 2.1 Introduction *29*
 - 2.1.1 Fundamental Considerations in Magnetism *32*
 - 2.1.2 Exchange *34*
 - 2.1.3 Itinerant Magnetism *35*
 - 2.1.4 Classes of Magnetic Materials *38*

2.1.4.1	Permanent Magnets	39
2.1.4.2	Other Applications	41
2.1.5	Finite-Temperature Magnetism	42
2.1.6	Magnetic Anisotropy	45
2.1.6.1	Phenomenology of Anisotropy	45
2.1.6.2	Microscopic Origin of Anisotropy	46
2.1.6.3	Temperature Dependence of Anisotropy	48
2.2	Nanomagnetic Phenomena of Atomic Origin	48
2.2.1	RKKY Exchange	48
2.2.2	Nanoparticle Magnetization	49
2.2.3	Finite-Size Scaling	50
2.2.4	Surface and Interface Anisotropy	51
2.3	Micromagnetics	52
2.3.1	Micromagnetic Free Energy	53
2.3.2	Micromagnetic Scaling	54
2.3.3	Magnetization Reversal	55
2.3.3.1	Magnetization Curling	55
2.3.3.2	Localized Nucleation	56
2.3.3.3	Pinning	57
2.3.4	Nanogeometry and Micromagnetism	58
2.3.4.1	Hard-Soft Two-Phase Nanostructures	58
2.3.4.2	Grain-Boundary Micromagnetism	60
2.3.4.3	Micromagnetic Topological Protection	61
2.3.5	Magnetization Dynamics	61
2.3.5.1	Spin Waves and Ferromagnetic Resonance	62
2.3.5.2	Nuclear Magnetic Resonance	63
2.3.5.3	Magnetic Viscosity	63
2.4	Spin-Dependent Transport	64
2.4.1	Magnetoresistance	65
2.4.1.1	Metallic Conductivity	65
2.4.1.2	Magnetoresistance Mechanisms	67
2.4.2	Anomalous Hall Effect	67
2.4.3	Topological Orders	68
2.4.4	Berry Phase	68
	Appendices	71
	Appendix 2.A: Functional Derivatives and Materials Equations	71
	Appendix 2.B: Relativistic Physics	72
	Appendix 2.C: Unit Conversion in Magnetism	74
	Acknowledgments	74
	References	74

Part Two Synthesis 81

3	Overview of Synthesis of Magnetic Nanomaterials	83
	<i>Xin Chu and Yanglong Hou</i>	
3.1	Introduction	83

3.2	General Synthesis Mechanism of Magnetic Nanoparticles	85
3.2.1	Top-Down Approaches	85
3.2.2	Bottom-Up Approaches	85
3.3	Typical Methods and Equipment of Magnetic Nanomaterials Synthetic Techniques: Chemical Approaches	85
3.3.1	Coprecipitation	85
3.3.1.1	General Mechanism of Coprecipitation Method for Magnetic Nanoparticles Synthesis	85
3.3.1.2	The Process and Influence Factors of Coprecipitation Method for Magnetic Nanoparticle Synthesis	86
3.3.1.3	Characteristics of Typical Magnetic Nanoparticles Synthesized with Coprecipitation Method	87
3.3.2	Hydrothermal and Solvent Thermal Synthesis	87
3.3.2.1	General Mechanism of Hydrothermal and Solvent Thermal Method for Magnetic Nanoparticles Synthesis	87
3.3.2.2	The Process and Influence Factor of Solvent Thermal Synthesis in Magnetic Nanoparticle Synthesis	87
3.3.2.3	Characteristics of Typical Magnetic Nanoparticles Synthesized with Hydrothermal	88
3.3.3	Thermal Decomposition	89
3.3.3.1	General Mechanism of Thermal Decomposition Method for Magnetic Nanoparticles Synthesis	89
3.3.3.2	The Influence Factors of Thermal Decomposition Method for Magnetic Nanoparticle Synthesis	89
3.3.3.3	The Typical Magnetic Nanoparticles Synthesized with Thermal Decomposition	91
3.3.4	Sol–Gel Method	91
3.3.4.1	General Mechanism of Sol–Gel Method for Magnetic Nanoparticles Synthesis	91
3.3.4.2	The Process and Influence Factors of Sol–Gel Method for Magnetic Nanoparticle Synthesis	92
3.3.4.3	Characteristics of Typical Magnetic Nanoparticles Synthesized with Sol–Gel Method	93
3.3.5	Ultrasonic Chemical Reactions	93
3.3.5.1	General Mechanism of Ultrasonic Chemical Reactions for Magnetic Nanoparticles Synthesis	93
3.3.5.2	The Process and Influence Factors of Ultrasonic Chemical Reactions for Magnetic Nanoparticle Synthesis	93
3.3.5.3	Characteristics of Typical Magnetic Nanoparticles Synthesized with Ultrasonic Chemical Reaction	94
3.3.6	Chemical Reduction	94
3.3.6.1	General Mechanism of Chemical Reduction Method for Magnetic Nanoparticles Synthesis	94
3.3.6.2	The Typical Reductive Agents Used in Chemical Reduction Method	95
3.3.6.3	Characteristics of Typical Magnetic Nanoparticles Synthesized with Chemical Reduction	95

3.3.7	Microemulsion Reactions	97
3.3.7.1	General Mechanism of Microemulsion Reactions for Magnetic Nanoparticles Synthesis	97
3.3.7.2	The Process and Influence Factors of Microemulsion Reactions for Magnetic Nanoparticle Synthesis	97
3.3.7.3	Characteristics of Typical Magnetic Nanoparticles Synthesized with Microemulsion Reactions	99
3.3.8	Microwave-Assisted Synthesis	100
3.3.8.1	General Mechanism of Microwave-Assisted Synthesis for Magnetic Nanoparticles Synthesis	100
3.3.8.2	The Process and Influence Factors of Microwave-Assisted Synthesis for Magnetic Nanoparticle Synthesis	100
3.3.8.3	Characteristics of Typical Magnetic Nanoparticles Synthesized with Microwave-Assisted Synthesis	101
3.3.9	Chemical Deposition	102
3.3.9.1	General Mechanism of Chemical Deposition Method for Magnetic Nanoparticles Synthesis	102
3.3.9.2	The Process and Influence Factors of Chemical Deposition Synthesis for Magnetic Nanoparticle Synthesis	102
3.3.9.3	Characteristics of Typical Magnetic Nanoparticles Synthesized with Chemical Deposition Synthesis	102
3.4	Typical Methods and Equipment of Magnetic Nanomaterials Synthetic Techniques: Physical Approaches	104
3.4.1	Metal Evaporation Method	104
3.4.1.1	General Mechanism of Metal Evaporation Method for Magnetic Nanoparticles Synthesis	104
3.4.1.2	The Process and Influence Factors of Metal Evaporation Synthesis for Magnetic Nanoparticle Synthesis	104
3.4.1.3	Characteristics of Typical Magnetic Nanoparticles Synthesized with Metal Evaporation Synthesis	105
3.4.1.4	The Limitation of Metal Evaporation Synthesis in Magnetic Nanoparticle Synthesis	107
3.4.2	High-Energy Ball Milling Method	108
3.4.2.1	General Mechanism of High-Energy Ball Milling Method for Magnetic Nanoparticles Synthesis	108
3.4.2.2	The Process and Influence Factors of High-Energy Ball Milling Method for Magnetic Nanoparticles Synthesis	108
3.4.2.3	Characteristics of Typical Magnetic Nanoparticles Synthesized with High-Energy Ball Milling Method	108
3.4.2.4	The Limitation of High-Energy Ball Milling Method in Magnetic Nanoparticle Synthesis	108
3.4.3	Plasma Method	109
3.4.3.1	General Mechanism of Plasma Method for Magnetic Nanoparticles Synthesis	109
3.4.3.2	The Process and Influence Factors of Plasma Method for Magnetic Nanoparticle Synthesis	109

3.4.3.3	Characteristics of Typical Magnetic Nanoparticles Synthesized with Plasma Method	110
3.4.3.4	The Limitation of Plasma Method in Magnetic Nanoparticle Synthesis	113
3.4.4	Other Methods	113
3.5	Conclusions and Perspectives	113
	References	114
4	Synthesis of Soft Magnetic Nanomaterials and Alloys	121
	<i>Song Lan and Matthew A. Willard</i>	
4.1	Introduction	121
4.2	Nanoparticles	123
4.3	Nanorods	127
4.4	Thin Films	134
4.5	Ribbons	136
4.5.1	Rapid Solidification	136
4.5.2	Crystallization	137
4.6	Conclusions	140
	References	141
5	Synthesis of Nanostructured Rare-Earth Permanent Magnets	147
	<i>Ming Yue and George C. Hadjipanayis</i>	
5.1	Introduction	147
5.1.1	Development of Nanostructured Rare-Earth Permanent Magnets	147
5.1.2	Techniques for Preparing Nanostructured REPM	149
5.1.2.1	Nanostructured Powders and Low-Dimensional Materials	149
5.1.2.2	Bulk Fully Dense Magnets	152
5.2	RCo_x -Based ($\text{R} = \text{Sm}, \text{Pr}, \text{Y}, \text{La}$) Nanostructured Magnets	155
5.2.1	RCo_x -Based Single-Phase Magnets	155
5.2.1.1	Magnetically Isotropic Magnets	155
5.2.1.2	Magnetically Anisotropic Magnets	156
5.2.2	RCo_x -Based Nanocomposite Magnets	158
5.2.2.1	Magnetically Isotropic Magnets	158
5.2.2.2	Magnetically Anisotropic Magnets	160
5.3	$\text{R}_2\text{Fe}_{14}\text{B}$ -Based ($\text{R} = \text{Pr}, \text{Nd}, \text{Tb}, \text{Dy}$) Magnets	161
5.3.1	$\text{R}_2\text{Fe}_{14}\text{B}$ -Based Single-Phase Magnets	161
5.3.1.1	Magnetically Isotropic Magnets	161
5.3.1.2	Magnetically Anisotropic Magnets	162
5.3.2	$\text{R}_2\text{Fe}_{14}\text{B}$ -Based Nanocomposite Magnets	163
5.3.2.1	Magnetically Isotropic Magnets	163
5.3.2.2	Magnetically Anisotropic Magnets	164
5.4	Conclusions and Perspectives	166
	References	166
6	Synthesis of Rare Earth Free Permanent Magnets	175
	<i>Shenqiang Ren and Jinbo Yang</i>	
6.1	Introduction	175

6.2	Tetragonal $L1_0$ FeCo	175
6.3	MnBi Low-Temperature Phase	179
6.4	Conclusions and Perspective	186
	Acknowledgment	187
	References	187
7	Synthesis and Properties of Magnetic Chalcogenide Nanostructures	191
	<i>Karthik Ramasamy, Soubantika Palchoudhury, and Arunava Gupta</i>	
7.1	Introduction	191
7.2	Synthesis Methods of Binary Magnetic Chalcogenide Nanostructures	192
7.2.1	Iron Sulfide Nanocrystals	192
7.2.2	Iron Selenide Nanocrystals	195
7.2.3	Europium Chalcogenide Nanocrystals	196
7.3	Synthesis Methods of Ternary and Higher Order Magnetic Chalcogenides Nanostructures	201
7.4	Structural and Magnetic Characterizations of Magnetic Chalcogenide Nanostructures	206
7.5	Potential Applications of Magnetic Chalcogenide Nanostructures	208
7.5.1	Spintronics Applications	208
7.5.2	Magnetocaloric Applications	209
7.5.3	Magneto-Optic Applications	210
7.5.4	Biomedical Applications	210
7.6	Conclusions and Perspectives	211
	Acknowledgments	212
	References	212
8	Magnetic Multicomponent Heterostructured Nanocrystals	217
	<i>P. Davide Cozzoli, Concetta Nobile, Riccardo Scarfiello, Angela Fiore, and Luigi Carbone</i>	
8.1	Introduction	217
8.2	Synthesis of Heterostructured Nanocrystals: Basic Concepts and Guiding Criteria	219
8.2.1	Synthesis of Single-Material Nanocrystals	219
8.2.2	Thermodynamics Underlying Heterostructure Formation	220
8.2.3	Liquid-Phase Epitaxy via Seeded Growth	222
8.3	Heterostructures with Core/Shell Geometries	223
8.3.1	Direct Heterogeneous Deposition	224
8.3.1.1	All-Metal Associations	226
8.3.1.2	Semiconductor/Transition-Metal Associations	231
8.3.1.3	Metal Oxide-Based Associations	231
8.3.2	Silica Coating	235
8.3.3	Shell Formation by Redox Replacement or Conversion Reactions	237
8.3.4	Shell Transformation via Cation-Exchange Reactions	240

8.3.5	Self-Controlled Nucleation-Growth, Thermally Induced Solid-State Atomic Diffusion and Phase Segregation	242
8.3.5.1	Self-Controlled Nucleation Growth	242
8.3.5.2	Thermally Induced Solid-State Diffusion and Phase Segregation	244
8.4	Nanohetero-Oligomer Architectures	245
8.4.1	Heterostructures Based on Nearly Isotropic-Shaped Material Domains	245
8.4.1.1	Direct Heterogeneous Nucleation	246
8.4.1.2	Postdeposition Coalescence-Crystallization and Solid-State Diffusion	254
8.4.1.3	Reactions at Liquid/Liquid Interfaces	254
8.4.1.4	Self-Regulated Homogeneous and Heterogeneous Nucleation	255
8.4.1.5	Reactions Induced Between Preformed HNCs	256
8.4.2	Heterostructures Based on Anisotropic-Shaped Material Sections	256
8.4.2.1	Site-Specific Heterogeneous Nucleation	259
8.4.2.2	Surfactant-Controlled Selective Heterogeneous Nucleation	264
8.4.2.3	Strain-Driven Heterostructure Formation	266
8.5	Conclusions	266
	Acknowledgment	267
	References	267
9	Wet-Phase Synthesis of Typical Magnetic Nanoparticles with Controlled Morphologies	291
	<i>Jiajia Liu, Jia Liu, Meng Xu, and Jiatao Zhang</i>	
9.1	Introduction	291
9.1.1	Yolk-Shell Nanoparticles	292
9.1.2	Dumbbell-Like Nanoparticles	297
9.1.3	Nanowires and Nanorods	299
9.1.3.1	Templating Synthesis Method	299
9.1.3.2	Solvothermal Method	301
9.2	Synthesis of Hollow/Porous Magnetic Nanoparticles	303
9.2.1	Hollow Nanoparticles	303
9.2.2	Porous Nanoparticles	310
9.2.3	Nanorings and Nanodisks	312
9.3	Conclusions and Perspectives	317
	Acknowledgment	317
	References	317
10	Self-Assembly of Co Nanocrystals Self-Assembled in 2D and 3D Superlattices: Chemical and Physical Specific Properties	327
	<i>Marie-Paule Pileni</i>	
10.1	Introduction	327
10.2	Control of Crystalline Structure of Nanoparticles (Nanocrystallinity) and the Nanocrystal Size	328
10.2.1	Synthesis of ϵ -Phase Co Nanocrystals	328
10.2.2	Syntheses of Amorphous and hcp Phases	329

10.2.3	Synthesis of fcc Phase	329
10.3	Nano-Kirkendall Effect on Co Nanocrystals: Influence of Size and Nanocrystallinity [51–54]	329
10.4	3D Self-Assemblies of Magnetic Supracrystals: Various Structures and Specific Behaviors	331
10.4.1	Amorphous Cobalt (Co _A) Nanoparticles Used as Building Blocks	331
10.4.2	Quasi Supracrystals Due to Magnetic Interactions between Nanocrystals [38]	331
10.5	3D Self-Assemblies of Magnetic Supracrystals: Physical Properties	333
10.5.1	Analogy between Supracrystals and Atomic Crystalline Structures [63]	333
10.5.2	Magnetic Properties of Supracrystals of Single Domain ϵ -Phase Co Nanocrystals, Co _e [68]	334
10.5.3	Mechanical Properties of Co _e Nanocrystals [73]	336
10.6	Conclusions	337
	Acknowledgment	338
	References	338

Part Three Applications 343

11	Magnetic Nanoparticles for Bioseparation, Biosensing, and Regenerative Medicine	345
	<i>Yiyuan Han, Min Wang, and Chenjie Xu</i>	
11.1	Introduction	345
11.2	Synthesis and Modification of High-Moment Magnetic Nanoparticles	346
11.3	Magnetic Nanomaterials for Bioseparation	347
11.3.1	Protein Separation	347
11.3.2	Bacteria Separation	350
11.3.3	Removal of Pollutants from Water	353
11.4	Magnetic Nanoparticles for Magnetic Biosensing	354
11.4.1	Magnetometer-Based Biosensing	355
11.4.2	Magnetic Resonance-Based Biosensing	356
11.5	Magnetic Nanoparticles for Regenerative Medicine	358
11.6	Challenges and Perspectives	360
	References	360
12	Magnetic Nanomaterials for Diagnostics	365
	<i>Zijian Zhou and Xiaoyuan Chen</i>	
12.1	Introduction	365
12.2	Biocompatibility of Magnetic Nanoparticles	366
12.2.1	Assessment of Biological Toxicity of Magnetic Nanoparticles	366
12.2.2	General Toxicity of Magnetic Nanoparticles	367
12.2.3	Design Considerations for Biocompatible Magnetic Nanoparticles	368

12.3	Surface Functionalization of Magnetic Nanomaterials	368
12.3.1	Tools and Rules of Surface Functionalization	368
12.3.2	Surface Functionalization for Phase Transfer	369
12.3.3	Surface Functionalization for Targeting	370
12.4	Magnetic Resonance Imaging (MRI)	372
12.4.1	Mechanism and Phenomenon of Magnetic Nanoparticles in MRI	372
12.4.2	Engineered Magnetic Nanoparticles as Enhanced MRI Contrast Agents	374
12.4.3	Portable microNMR Diagnostic Device	377
12.5	Magnetoacoustic Tomography (MAT)	378
12.5.1	Basic Principles of MAT	378
12.5.2	Magnetic Nanoparticles as MAT Agents	380
12.6	Magnetic Particle Imaging (MPI)	381
12.6.1	Basic Principles of MPI	381
12.6.2	Magnetic Nanoparticles as MPI Agents	383
12.7	Multimodality Imaging	384
12.7.1	Magnetic Nanoparticles for Multimodality Imaging	384
12.7.2	Engineered Multifunctional Magnetic Nanoparticles	385
12.8	Conclusions and Perspectives	386
	References	387
13	Magnetic Nanomaterials for Therapy	393
	<i>Daishun Ling and Taeghwan Hyeon</i>	
13.1	Introduction	393
13.2	Imaging-Guided Therapy Using Magnetic Nanomaterials	393
13.2.1	Imaging-Guided Chemotherapy	394
13.2.2	Imaging-Guided Photodynamic Therapy	396
13.2.3	Imaging-Guided Photothermal Therapy	397
13.2.4	Imaging-Guided Multimodal Therapy	400
13.2.5	Imaging-Guided Surgery	403
13.2.6	Predicting Therapeutic Nanomedicine Efficacy	404
13.3	Magnetic Hyperthermia	407
13.3.1	Thermal Ablation	407
13.3.2	Apoptotic Hyperthermia	410
13.3.3	Hyperthermia-Controlled Drug Release	411
13.3.4	Combining Magnetic Hyperthermia with Other Therapeutics	414
13.4	Targeted Drug Delivery	416
13.4.1	<i>In vitro</i> Magnetically Controlled Drug Delivery	416
13.4.2	<i>In Vivo</i> Magnetically Controlled Drug Delivery	419
13.5	Targeted Gene Delivery	419
13.5.1	<i>In Vitro</i> Magnetofection	420
13.5.2	<i>In Vivo</i> Gene Delivery Monitoring	425
13.6	Manipulation of Cellular Functions	425
13.7	Conclusions and Perspectives	429
	Acknowledgments	431
	References	431

14	Magnetic Nanomaterials for Data Storage	439
	<i>Jung-Wei Liao, Hong-Wei Zhang, and Chih-Huang Lai</i>	
14.1	Introduction: Magnetic Data Storage and its Requirements on Magnetic Nanomaterials	439
14.2	Nanostructured Magnetic Thin Films for Data Storage: Overview of Perpendicular Recording (PMR) Media	442
14.2.1.1	Overall Layer Structures of Co-Based Magnetic Thin Films	442
14.2.1.2	Film Morphologies and Crystalline Structures of the Co-Based Recording Layer	442
14.2.1.3	Intermediate Layers	445
14.3	Nanostructured Magnetic Thin Films for Data Storage: Overview of FePt Media for Heat-Assisted Magnetic Recording (HAMR)	446
14.3.1.1	Overview of L1 ₀ FePt for Heat-Assisted Magnetic Recording (HAMR)	447
14.3.1.2	Development of L1 ₀ FePt Film for Magnetic Recording	447
14.4	Monodisperse Magnetic Nanoparticles: Synthesis, Phase Transition, Orientation Control, and Nanocomposites	450
14.4.1	Synthesis, Phase Transition, and Size Control of FePt Nanoparticles	451
14.4.2	Orientation Control	453
14.5	Patterned Magnetic Nanostructures for Bit Patterned Media Through Bottom-Up Approach: Self-Assembly and Guided Assembly of Block Copolymer	454
14.5.1	Working Principles of Bit Patterned Media	454
14.5.1.1	Self-Assembly and Guided Assembly of Block Copolymer (PCB)	455
14.6	Patterned Magnetic Nanostructures for Bit Patterned Media Through Top-Down Approach: Lithograph	462
14.6.1	Magnetic Materials for an Approach of an Etching Back Process	462
14.6.2	Magnetic Materials for an Approach of a Prepatterned Substrate	463
14.6.3	Magnetic Materials for Template Growth	464
14.7	Conclusions and Perspectives	465
	References	467
15	Magnetic Nanomaterials for Electromagnetic Wave Absorption	473
	<i>Ling Bing Kong, Lie Liu, Zhihong Yang, Sean Li, and Tianshu Zhang</i>	
15.1	Introduction	473
15.2	Magnetic Nanosized Powders and Composites	474
15.2.1	Metallic Magnetic Nanosized Powders	474
15.2.1.1	Chemical Routes	474
15.2.1.2	DC Arc-Discharging Method	490
15.2.1.3	High-Energy Ball Milling	493
15.2.1.4	Physical Compaction	499
15.2.2	Nonmetallic Magnetic Nanosized Powders	504
15.3	Nanosized Carbon Materials with Magnetic Components	506
15.4	Concluding Remarks	509
	References	510

16	Magnetic Nanomaterials for Water Remediation	515
	<i>Peirui Liu and Yu Hong</i>	
16.1	Introduction	515
16.2	Magnetic Nanomaterials for Adsorption and Removal of Pollutants in Water	516
16.2.1	Adsorption and Removal of Heavy Metals	516
16.2.2	Adsorption and Removal of Dyes	521
16.2.3	Adsorption and Removal of Other Pollutants	524
16.3	Magnetic Nanomaterials for Catalytic Degradation of Wastewater	525
16.3.1	Photochemical Catalysis	525
16.3.2	Fenton Degradation	526
16.3.3	Other Catalytic Degradation Methods	527
16.4	Magnetic Nanomaterials for Wastewater Resources Recovery	529
16.5	Magnetic Nanomaterials for Monitoring and Analysis Technologies	530
16.5.1	Detection and Analysis of Trace Elements and Other Common Pollutants	531
16.5.2	Detection and Analysis of Pathogen	533
16.6	Conclusion and Perspectives	534
	Acknowledgment	535
	References	535
	Index	547