

Contents

<i>Preface</i>	xiii
<i>Biographies</i>	xv
<i>Contributors</i>	xvii
1. Overview of Nanoscience in the Environment	1
<i>Mohamed Baalousha and Jamie R. Lead</i>	
1.1 Introduction	1
1.2 History	2
1.3 Definitions	3
1.4 Investment and International Efforts	6
1.5 Development: Four Anticipated Generations	6
1.6 Applications of Nanotechnology	7
1.7 Potential Benefits of Nanotechnology	8
1.7.1 Environmental	8
1.7.2 Human Health	9
1.8 Potential Adverse Effects of Nanomaterials	10
1.8.1 Environmental	10
1.8.2 Human Health	12
1.9 Classification	12
1.9.1 Chemistry	12
1.9.2 Origin	13
1.9.3 Size	13
1.9.4 State	14
1.10 Sources of Nanomaterials in the Environment	14
1.11 Properties of Nanomaterials	14
1.12 Nanomaterial Structure–Toxicity Relationship	15
1.13 Environmental Fate and Behaviour of Nanomaterials	16
1.13.1 Fate in Air	17
1.13.2 Fate in Water	17
1.13.3 Fate in Soil	19
1.14 Potential for Human Exposure	20
1.15 Detection and Characterization of Nanomaterials	21
1.16 Issues to be Addressed	21
1.16.1 Nomenclature	21

1.16.2	Future Development and Risk	23
1.16.3	Dosimetry	23
1.16.4	Methods of Detection and Characterization	23
1.16.5	Environmental Fate of Nanomaterials and their (Eco)Toxicology	23
1.17	Conclusion	24
1.18	References	24
2.	Nanomaterials: Properties, Preparation and Applications	31
	<i>Paul Christian</i>	
2.1	Overview	31
2.2	Introduction	32
2.3	Nanoparticle Architecture	35
2.3.1	Nanoparticle Surface	38
2.3.2	Charge Stabilisation	41
2.3.3	Steric Stabilisation	42
2.4	Particle Properties	45
2.4.1	Surface Plasmon Resonance	45
2.4.2	Catalysis	46
2.4.3	Quantum Confinement	47
2.4.4	Mechanical Performance	48
2.4.5	Magnetic Properties	49
2.4.6	Interfacial Properties	49
2.4.7	Other Properties	50
2.5	Nanoparticle Preparation	53
2.5.1	The Challenges of Nanoparticle Synthesis: Scale Up	53
2.5.2	Reactivity	53
2.5.3	Dispersability	53
2.5.4	Cost	54
2.5.5	Methods: Natural Sources	54
2.5.6	Top Down	55
2.5.7	Bottom Up	55
2.5.8	Metal Nanoparticles	59
2.5.9	Carbon	60
2.5.10	Graphene	62
2.5.11	Carbon Black	62
2.5.12	Inorganic Compounds	63
2.5.13	Polymers	64
2.6	Applications of Nanoparticles and Nanotechnology	65
2.6.1	The Past	65
2.6.2	The Present and Near Future	67
2.7	Implication for Environmental Issues	72
2.8	Conclusions	73
2.9	References	73

3. Size/Shape–Property Relationships of Non-Carbonaceous Inorganic Nanoparticles and Their Environmental Implications 79

Deborah M. Aruguete, Juan Liu and Michael F. Hochella, Jr

3.1	Introduction	79
3.2	Inorganic Nanoparticle Anatomy	80
3.3	Redox Chemistry of Nanoparticles	81
3.3.1	Photoredox Chemistry in Semiconductor Nanoparticles	81
3.3.2	Redox Chemistry in Other Nanoparticle Systems	84
3.4	Size Effects in Nanoparticle Sorption Processes	87
3.5	Nanoparticle Fate: Dissolution and Solid State Cation Movement	89
3.5.1	Basic Energetic and Kinetic Considerations of Nanoparticle Dissolution	89
3.5.2	Effects of Nanoparticle Morphology	91
3.5.3	Effects of Nanoparticle Coatings and External Substances	92
3.5.4	Case Study: The Dissolution of Lead Sulfide Nanoparticles	94
3.5.5	Solid State Cation Movement in Nanoparticles	96
3.6	Effect of Nanoparticle Aggregation on Physical and Chemical Properties	98
3.7	Environmental Implications: General Discussion, Recommendations and Outlook	99
3.8	References	101

4. Natural Colloids and Nanoparticles in Aquatic and Terrestrial Environments 109

Mohamed Baalousha, Jamie R. Lead, Frank von der Kammer and Thilo Hofmann

4.1	Introduction	109
4.2	Definition	112
4.3	Major Types of Environmental Colloids	112
4.3.1	Inorganic Colloids	114
4.3.2	Organic Macromolecules	117
4.4	Intrinsic Properties of Environmental Colloidal Particles	121
4.4.1	Size	121
4.4.2	Surface Charge	121
4.4.3	Surface Coating by Natural Organic Matter	123
4.4.4	Fractal Dimension	124
4.5	Interaction Forces Between Colloidal Particles	126
4.5.1	DLVO Theory	127
4.5.2	Stability Criteria	129
4.5.3	Aggregation Kinetics	129
4.5.4	Non-DLVO Interactions	130
4.6	Fate and Behaviour of Colloids in Aquatic Systems	136
4.6.1	Aggregation	136

4.6.2	Disaggregation: Effect of Natural Organic Matter	140
4.6.3	Sedimentation Behaviour	141
4.7	Fate and Behaviour of Colloids and Nanoparticles in Porous Media	141
4.7.1	Saturated Porous Media	143
4.7.2	Unsaturated Porous Media	146
4.8	Conclusion	147
4.9	References	147
5.	Atmospheric Nanoparticles	163
	<i>Aur�lie Charron and Roy M. Harrison</i>	
5.1	Introduction	163
5.2	Sources of Atmospheric Nanoparticles	164
5.2.1	Sources of Primary Nanoparticles	164
5.2.2	Secondary Sources	175
5.3	Chemical Composition of Atmospheric Nanoparticles	178
5.4	Fate and Behaviour of Atmospheric Nanoparticles	181
5.5	Atmospheric Concentrations	182
5.5.1	Spatial Variations	182
5.5.2	Temporal Variations	185
5.6	Measurement Methods for Atmospheric Nanoparticles	187
5.6.1	Particle Number Concentration	189
5.6.2	Surface Area	193
5.6.3	Mass Concentration	194
5.6.4	Chemical Composition	196
5.7	Conclusions	200
5.8	References	201
6.	Analysis and Characterization of Manufactured Nanoparticles in Aquatic Environments	211
	<i>Martin Hassell�v and Ralf Kaegi</i>	
6.1	Introduction	211
6.1.1	Nanoparticles in the Aquatic Environment	212
6.1.2	Concepts and Definitions Relating to Analysis and Characterization	212
6.2	Nanoparticle Analysis and Characterization Methods	214
6.2.1	Important Nanoparticle Characteristics	214
6.2.2	Sampling, NP Extraction, Sample Preparations	224
6.2.3	Light Scattering Methods	224
6.2.4	Other Electromagnetic Scattering Methods	229
6.2.5	Fractionation and Separation Methods	230
6.2.6	Microscopic Methods	237
6.2.7	Spectroscopic Methods	249
6.2.8	Surface Area Measurements with Nitrogen Gas Adsorption	251

6.2.9	Method Validation	251
6.3	Analytical Test Strategy in NP Exposure Assessment	252
6.3.1	Initial Material Characterization	252
6.3.2	Fate and Behaviour Assessment	252
6.3.3	Exposure Characterization in Effect Assessment Experiments	253
6.3.4	Monitoring Nanopollution	254
6.4	Conclusions	255
6.5	Acknowledgements	256
6.6	References	256
7.	Ecotoxicology of Manufactured Nanoparticles	267
	<i>Simon C. Apte, Nicola J. Rogers and Graeme E. Batley</i>	
7.1	Introduction	267
7.2	Physico-Chemical Transformation of Nanoparticles	269
7.2.1	Particle Dispersion and Aggregation	270
7.2.2	Nanoparticle Dissolution	272
7.2.3	Oxidation	273
7.2.4	Adsorption Reactions	275
7.3	Mechanisms of Nanoparticle Toxicity in the Environment	275
7.3.1	Exposure Routes	275
7.3.2	Nanoparticle Interactions with Cells: Cellular Uptake	277
7.3.3	Toxicity Mechanisms	280
7.3.4	Bioaccumulation	283
7.4	Development of Valid/Realistic Toxicity Testing Protocols	284
7.5	Review of Ecotoxicity Studies	285
7.5.1	Overview	285
7.5.2	Carbon-Based Nanoparticles	289
7.5.3	Metal Oxides	293
7.5.4	Silver	296
7.5.5	Copper	298
7.5.6	Quantum Dots	298
7.5.7	Iron	299
7.6	General Conclusions and Future Directions	300
7.7	References	301
8.	Exposure to Nanoparticles	307
	<i>Robert J. Aitken, Karen S. Galea, C. Lang Tran and John W. Cherrie</i>	
8.1	Introduction	307
8.2	Physical Characteristics and Properties of Nanoparticles	309
8.2.1	Terminology and Definitions	309
8.2.2	Nanoparticle Types	311

6.2.9	Method Validation	251
6.3	Analytical Test Strategy in NP Exposure Assessment	252
6.3.1	Initial Material Characterization	252
6.3.2	Fate and Behaviour Assessment	252
6.3.3	Exposure Characterization in Effect Assessment Experiments	253
6.3.4	Monitoring Nanopollution	254
6.4	Conclusions	255
6.5	Acknowledgements	256
6.6	References	256
7.	Ecotoxicology of Manufactured Nanoparticles	267
	<i>Simon C. Apte, Nicola J. Rogers and Graeme E. Batley</i>	
7.1	Introduction	267
7.2	Physico-Chemical Transformation of Nanoparticles	269
7.2.1	Particle Dispersion and Aggregation	270
7.2.2	Nanoparticle Dissolution	272
7.2.3	Oxidation	273
7.2.4	Adsorption Reactions	275
7.3	Mechanisms of Nanoparticle Toxicity in the Environment	275
7.3.1	Exposure Routes	275
7.3.2	Nanoparticle Interactions with Cells: Cellular Uptake	277
7.3.3	Toxicity Mechanisms	280
7.3.4	Bioaccumulation	283
7.4	Development of Valid/Realistic Toxicity Testing Protocols	284
7.5	Review of Ecotoxicity Studies	285
7.5.1	Overview	285
7.5.2	Carbon-Based Nanoparticles	289
7.5.3	Metal Oxides	293
7.5.4	Silver	296
7.5.5	Copper	298
7.5.6	Quantum Dots	298
7.5.7	Iron	299
7.6	General Conclusions and Future Directions	300
7.7	References	301
8.	Exposure to Nanoparticles	307
	<i>Robert J. Aitken, Karen S. Galea, C. Lang Tran and John W. Cherrie</i>	
8.1	Introduction	307
8.2	Physical Characteristics and Properties of Nanoparticles	309
8.2.1	Terminology and Definitions	309
8.2.2	Nanoparticle Types	311

8.2.3	Nanoparticle Production Processes	314
8.2.4	Nanoparticle Behaviour	316
8.3	Nanoparticle Exposure	319
8.3.1	Exposure Scenarios	319
8.3.2	Exposure Metrics	327
8.3.3	Methods of Measuring and Characterising Exposure to Nanoparticles	330
8.3.4	Studies Investigating Nanoparticle Exposure	338
8.3.5	Numbers of People Potentially Exposed	344
8.4	Control of Exposure	346
8.4.1	Introduction	346
8.4.2	Inhalation Exposure	347
8.4.3	Dermal Exposure	349
8.4.4	Ingestion Exposure	350
8.5	Discussion	350
8.6	References	353
9.	Human Toxicology and Effects of Nanoparticles	357
	<i>Vicki Stone, Martin J.D. Clift and Helinor Johnston</i>	
9.1	Introduction	357
9.1.1	Toxicology – What Is It?	357
9.1.2	Particle Toxicology	357
9.1.3	Risk Assessment	358
9.2	Ultrafine Particle Toxicology	360
9.2.1	Air Pollution	360
9.2.2	Testing the Ultrafine Particle Hypothesis	361
9.2.3	Reactive Oxygen Species and Oxidative Stress	363
9.2.4	Uptake of Nanoparticles into Cells	365
9.2.5	Interaction of Nanoparticles with Defence Mechanisms	366
9.2.6	Nanoparticle Interactions with Other Pollutants and Molecules	367
9.3	Engineered Nanoparticles	368
9.3.1	Fullerenes	369
9.3.2	Nanotubes and Other Fibre-Like Nanostructures	370
9.3.3	Metals	373
9.3.4	Metal Oxides	374
9.3.5	Quantum Dots	377
9.4	Relating Physico-Chemical Properties to Toxicity: Structure-Activity Relationships	379
9.5	Suggestions for Future Study Designs	381
9.6	Conclusions	381
9.7	Abbreviations	382
9.8	References	382

10. Risk Assessment of Manufactured Nanomaterials	389
<i>Sophie A. Rocks, Simon J. Pollard, Robert A. Dorey, Paul T. C. Harrison, Len S. Levy, Richard D. Handy, John F. Garrod and Richard Owen</i>	
10.1 Introduction	389
10.2 Risk Assessment Process	391
10.3 Nanomaterials – Issues for Risk Assessment	399
10.4 Assembling Evidence for Safety and Intervention	403
10.5 International Case Studies	406
10.6 Data Gaps in Risk Assessment of Nanomaterials	407
10.7 Summary	410
10.8 References	417
<i>Index</i>	423