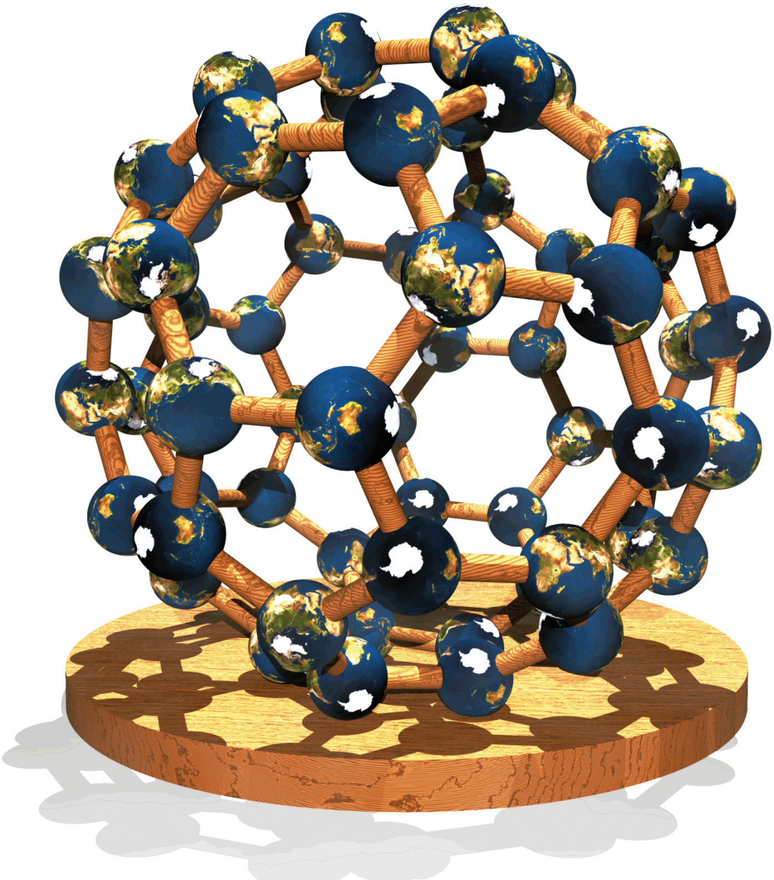
Nature's Nanostructures

Edited by

Amanda S. Barnard & Haibo Guo



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Preface

As *nanoscience* matures into *nanotechnology*, products containing nanomaterials are entering our lives. For those of us who work with nanomaterials professionally, it is an exciting time, filled with pride and expectation. However, for those outside the research community, this is a time of change that can be very confronting. What is nanotechnology, and what impact will it have upon our lives? How do we reconcile with the notion of these new "functional" pieces of matter that are too small to defect, or avoid. Irrespective of our perspective, it is both humbling and comforting to realize nanomaterials are actually not as new as we think, and that Nature has been producing nanomaterials since the dawn of time. This is a fascinating realization that inevitably leads to these questions: What are these natural nanomaterials made of? What do they look like? Where can we find them? And the most tantalizing, what can they do?

In this book, some of the leading researchers in the world share their studies of Nature's nanostructures, and we see that there is a lot to be learned from the elegant ways that Nature deals with the complexity of the nanoscale. While we struggle to refine our laboratory techniques, Nature's own laboratory has perfected the production of a range of highly selective nanomaterials. We are first introduced to this area by Michael F. Hochella and our plenary authors, who describe a variety of naturally occurring inorganic nanoparticles, in the context of the general assessment and a global budget for one of Earth's last unexplored major geochemical components.

We follow this introduction with a section dedicated to inorganic nanostructures produced on Earth (often referred to as nanominerals), opening with a discussion of physical and chemical properties of nanominerals by keynote author R. Lee Penn. This is followed by a detailed account of some of the most ubiquitous nanoparticles on Earth, iron oxides, which can form in a variety of different sizes, shape, structures and magnetization states (depending upon their environment). Of course, the study of nanominerals is not restricted to experimental techniques, and Salvy Russo and Andrew Hung describe ways that advanced computer simulation and theoretical modeling can help us determine how to model and predict how different sizes, shapes, and structures are formed. We then move on to nanomaterials that are rarer in Nature, such as gold nanoparticles in ores, described by Robert Hough and colleagues, and diamondoids extracted from oil, described by Christoph Bostedt and colleagues. In all of these cases, the natural nanomaterials have "positive curvature" (that is, they present as small solid particles); so we conclude this section by considering the opposite position. The final chapter of this section by Huifang Xu describes natural nanomaterials with "negative curvature," and explains the role of these nanosize pores (or voids) in regulating reactivity and transport of uranium in subsurface sediments.

Nanomaterials are not the only thing Nature has beaten us to; Nature has developed its own nanotechnology too. In Part II, we reveal some of the ways that Nature combines nanoparticles to form more complex structures, each with a specific application in mind. The vast majority of these applications are in the realm of biology, and keynote authors Jun Wu, Juming Yao, and Yurong Cai describe how our own bodies contain bones with hierarchical structure based on nanoparticles. We then turn our attention back to iron oxides and see how the smallest life forms use these magnetic nanoparticles, in a chapter by André Körnig and Damien Faivre. Bacteria are not the only life forms to use magnetic nanoparticles, and Ilia A. Solov'yov and Walter Greiner explain the properties and function of nanoscale magnetoreceptors in birds. In each case, these nanoparticles have not been inhaled, ingested or inserted but are formed *in situ* by the organism, in an environment that is very different from that of nanominerals. To understand the formation mechanisms, computer simulations are again instructive, and John H. Harding and colleagues explain how modeling the nucleation and growth of biomaterials to aid in understanding. This section concludes with a chapter by Ainsley E. Seago and Vinodkumar Saranathan, who focus on some of Nature's nanotechnology residing outside the body, in the beautiful photonic crystals decorating the wings and exoskeletons of beetles.

Both Earth and its inhabitants have lived with (and benefited from) Nature's nanostructures for millennia, but as our Part III keynote authors Frans J. M. Rietmeijer and Joseph A. Nuth show us that some nanoparticles are "out of this world." While nanoparticles forming in space are almost certainly well beyond our reach, they are not beyond our understanding, and we can still learn a lot about the large molecules and nanograins in interstellar space, as described by A. G. G. M. Tielens, and those closer to home in our own solar system, as described by Ingrid Mann. In the final chapter of this section, we converge still closer to Earth, and Tuukka Petäjä and colleagues introduce us to the formation and growth of nanoparticles in the atmosphere, and even the air we breathe.

So as we can see, nanomaterials are all around us: in the Earth, the air and the heavens. But does that mean that all nanomaterials behave in these predictable ways? Of course not. The majority of the nanotechnology community is focused on producing an array of different nanomaterials that do not exist in Nature and do things that natural nanostructures cannot. These "engineered" nanomaterials can have very different properties and can respond to the natural environment in a very different way. However, once these engineered nanomaterials enter the natural world, they become a permanent part of it, and as we increase the recyclability and biodegradability of our products, the probability of this occurring approaches 100 percent.

For this reason, Part IV of this book focuses on the interaction of manmade nanoparticles with the natural world. At this stage, these interactions are dominated by inadvertently and intentionally produced nanomaterials (a consequence of modern life) as described in our keynote chapter by Pratim Biswas and colleagues. A more detailed account of the nanoparticles on and near roadways (which many of us travel on everyday) is then provided by Yifang Zhu. Guodong Yuan and Shin-Ichiro Wada then discuss allophane and imogolite nanoparticles in soils and describe the role they play in environmental remediation and control. We conclude the book with a study of the interaction and transformation of laboratory-synthesized engineered nanostructures in the natural environment by Priyanka Bhattacharya, Emppu Salonen, and Pu Chun Ke, where we are left to ponder whether Nature will cope with our nanostructures as well as we have coped with hers.

This book represents the first collection of its type, bringing together studies from astronomy, physics, chemistry, materials science, engineering, geology and geophysics, environmental science, agricultural science, entomology, molecular biology and health. It would not have been possible without the tireless efforts of all involved, and we would like to thank all the authors for their wonderful contributions. We would also like to thank Dr. Lin Lai for his assistance in reviewing the chapters and Yunjing Zhang for her meticulous help in editing the book.

We hope you enjoy learning all about Nature's nanostructures.

Amanda S. Barnard
Haibo Guo

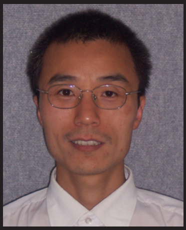
"At a time when we are concerned about the potential hazards of engineered nanomaterials, this book gives a timely and delightful overview of the variety of nanoparticles that exist in our environment — from noble metal nanoparticles in ore systems and nanodust in the solar system to magnetic nanoparticles in homing pigeons and photonic crystals in beetles. It is an enjoyable and a useful companion for anyone interested in knowing about the potential hazards of nanomaterials and those seeking inspiration from nature to create functional materials."

Dr Ai Lin Chun
Senior Editor, *Nature Nanotechnology*

While humanity strives to synthesize and utilize functional nanomaterials, nature's own laboratory has perfected the production of a range of highly selective nanomaterials. Natural nanomaterials (and even natural nanotechnologies) are all around us, and this ubiquity inevitably raises questions such as What are these natural nanomaterials made of? Where can we find them? What can they do? Answering these questions will lead to a better understanding of the world around us and facilitate new and environmentally friendly ways of creating and manipulating nanoscale materials for the next generation of new technologies.

This book represents the first collection of its type and is truly multidisciplinary. The compilation brings together studies from astronomy, physics, chemistry, materials science, engineering, geology and geophysics, environmental science, agricultural science, entomology, molecular biology, and health and is therefore an invaluable resource for learning how various scientists approach similar problems.

Amanda S. Barnard is leader of the Virtual Nanoscience Laboratory at the Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia's national science agency. She has a BSc and PhD in physics from RMIT University, Australia, and has held research positions at Argonne National Laboratory, USA, and the University of Oxford, UK. Using thermodynamic theory and first-principles computer simulations, she is a pioneer in the mapping of nanomorphology and the environmental stability of nanomaterials (thermodynamic cartography) and in the development of structure/property relationships for predicting the reliability of nanoparticles in high-performance applications.



Haibo Guo is a postdoctoral fellow and an early-career researcher at Virtual Nanoscience Laboratory, led by Dr Amanda Barnard. He received his BS in 2001 and PhD in 2006 from Tsinghua University, Beijing, China. His research interests include modeling and simulation of surfaces and interfaces in environmental and energy sciences.

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