U.S. Department of Energy
Office of Science

The Beauty of Nanoscale Science

Summary

Nanoscience ¾ the study of matter at the atomic scale ¾ takes us into a realm where the properties of materials are dramatically different. It is a realm demanding new tools and new understanding, but it may hold the key to a second industrial revolution. The aim is to gain control of materials and devices at the atomic and molecular level, allowing us to design materials with properties tailored to specific needs such as strong, lightweight materials; solar energy conversion; and new lubricants.

In his address to the annual meeting of the American Association for the Advancement of Science, Jack Marburger, the President's Science Advisor, spoke of the importance of probing the frontiers of complexity. By that he meant the atom-by-atom understanding of matter and the subsequent unprecedented ability to design and construct new materials with properties that are not found in nature.

"The revolution I am describing," he said, "is one in which the notion that everything is made of atoms finally becomes operational. … We can actually see how the machinery of life functions, atom-by-atom. We can actually build atomic scale structures that interact with biological or inorganic systems and alter their functions. We can design new tiny objects "from scratch" that have unprecedented optical, mechanical, electrical, chemical, or biological properties that address needs of human society."

The revolution that Dr. Marburger describes required two developments: First, the development of a set of major instruments and tools to probe and manipulate matter at the atomic scale such as the synchrotron x-ray and neutron scattering sources, the electron microscopes, and even the technologies for sequencing entire genomes quickly and accurately; and second, the development of high-performance computers.

The Office of Science has played a major role, indeed sometimes *the* major role, in both. This impact results from a deliberate philosophy of identifying seminal challenges and establishing coordinated programs that transcend what individuals alone can do. This is a unique attribute of the Office of Science, and it is one of our strengths. It is also what helps to distinguish research at our laboratories from that in the Nation's universities.

As we look to the coming years, the challenges are greater still. The new millennium takes us deep into the world of complexity described by Jack Marburger. Here, simple structures interact to create new phenomena and assemble themselves into devices. Here also, large complicated structures can be designed atom by atom for desired characteristics. New tools, new understanding, and a developing convergence of the disciplines of physics, chemistry, materials science, biology, computation, and engineering will enable us to build on our 20th Century successes and begin to ask and solve questions that were, until the 21st Century, the stuff of science fiction.

For example, can we harness, control, or mimic the exquisite complexity of Nature? Enormous energy savings, pollution reduction, and productivity increases would be achieved by the development of materials and systems with the enhanced properties seen in Nature, including the ability to self-assemble, self-repair, sense, respond, and evolve.

In many cases, accomplishment of these goals may appear to be beyond our reach, but no more so perhaps than optical tweezers, polymerase chain reaction, or gene therapy appeared a few years ago. We may or may not be able to reproduce all the characteristics of natural systems and tailor them to nonbiological needs. However, the study of Nature can clearly guide us and lead to achievements of great value that would not otherwise be made. Nature's achievements are therefore benchmarks for our increasing control of materials and materials systems. This is, perhaps, the ultimate goal.

Nature tells us it can be done and provides us with examples to serve as our models. We learn about Nature's design rules and try to mimic green plants that capture solar energy, or genetic variation as a route to "self-improvement" and optimized function. These concepts may seem fanciful, but with the revolution now taking place in biology, progressing from DNA sequence to structure and function, the possibilities seem endless.

Now is the time. We can now do this research, make these breakthroughs, and enhance our lives as never before imagined. The work of the past few decades has taken us to this point, solving many of the problems that underlie these challenges, teaching us how to approach problems of complexity, giving us the confidence needed to achieve these goals.

This work also gave us the ability to compute on our laps with more power than the Apollo astronauts had on their missions to the moon. It taught us to engineer genes, "superconduct" electricity, visualize individual atoms, build plastics 10 times stronger than steel, and put lasers on chips for portable CD players. We are ready to take the next steps.

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