

Building crystalline materials from nanoparticles and DNA

13 October 2011

Nature is a master builder. Using a bottom-up approach, nature takes tiny atoms and, through chemical bonding, makes crystalline materials, like diamonds, silicon and even table salt. In all of them, the properties of the crystals depend upon the type and arrangement of atoms within the crystalline lattice.

Now, a team of Northwestern University scientists has learned how to top nature by building crystalline materials from [nanoparticles](#) and DNA, the same material that defines the [genetic code](#) for all [living organisms](#).

Using nanoparticles as "atoms" and DNA as "bonds," the scientists have learned how to create crystals with the particles arranged in the same types of atomic lattice configurations as some found in nature, but they also have built completely new structures that have no naturally occurring mineral counterpart.

The basic design rules the Northwestern scientists have established for this approach to nanoparticle assembly promise the possibility of creating a variety of new materials that could be useful in catalysis, electronics, optics, [biomedicine](#) and energy generation, storage and conversion technologies.

The new method and design rules for making crystalline materials from [nanostructures](#) and DNA will be published Oct. 14 by the journal *Science*.

"We are building a new periodic table of sorts," said Professor Chad A. Mirkin, who led the research. "Using these new design rules and nanoparticles as 'artificial atoms,' we have developed modes of controlled crystallization that are, in many respects, more powerful than the way nature and chemists make [crystalline materials](#) from atoms. By controlling the size, shape, type

and location of nanoparticles within a given lattice, we can make completely new materials and arrangements of particles, not just what nature dictates."

Mirkin is the George B. Rathmann Professor of Chemistry in the Weinberg College of Arts and Sciences and professor of medicine, chemical and biological engineering, biomedical engineering and materials science and engineering and director of Northwestern's International Institute for Nanotechnology (IIN).

"Once we have a certain type of lattice," Mirkin said, "the particles can be moved closer together or farther apart by changing the length of the interconnecting DNA, thereby providing near-infinite tunability."

"This work resulted from an interdisciplinary collaboration that coupled synthetic chemistry with theoretical model building," said coauthor George C. Schatz, a world-renowned theoretician and the Charles E. and Emma H. Morrison Professor of Chemistry at Northwestern. "It was the back and forth between synthesis and theory that was crucial to the development of the design rules. Collaboration is a special aspect of research at Northwestern, and it worked very effectively for this project."

In the study, the researchers start with two solutions of nanoparticles coated with single-stranded DNA. They then add DNA strands that bind to these DNA-functionalized particles, which then present a large number of DNA "sticky ends" at a controlled distance from the particle surface; these sticky ends then bind to the sticky ends of adjacent particles, forming a macroscopic arrangement of nanoparticles.

Different crystal structures are achieved by using different combinations of nanoparticles (with varying sizes) and DNA linker strands (with

controllable lengths). After a process of mixing and heating, the assembled particles transition from an initially disordered state to one where every particle is precisely located according to a crystal lattice structure. The process is analogous to how ordered atomic crystals are formed.

The researchers report six design rules that can be used to predict the relative stability of different structures for a given set of nanoparticle sizes and DNA lengths. In the paper, they use these rules to prepare 41 different crystal structures with nine distinct crystal symmetries. However, the design rules outline a strategy to independently adjust each of the relevant crystallographic parameters, including particle size (varied from 5 to 60 nanometers), crystal symmetry and lattice parameters (which can range from 20 to 150 nanometers). This means that these 41 crystals are just a small example of the near infinite number of lattices that could be created using different nanoparticles and DNA strands.

Mirkin and his team used gold nanoparticles in their work but note that their method also can be applied to nanoparticles of other chemical compositions. Both the type of nanoparticle assembled and the symmetry of the assembled structure contribute to the properties of a lattice, making this method an ideal means to create materials with predictable and controllable physical properties.

Mirkin believes that, one day soon, software will be created that allows scientists to pick the particle and DNA pairs required to make almost any structure on demand.

More information: The *Science* paper is titled "Nanoparticle Superlattice Engineering with DNA."

Provided by Northwestern University
APA citation: Building crystalline materials from nanoparticles and DNA (2011, October 13) retrieved 24 November 2020 from <https://phys.org/news/2011-10-crystalline-materials-nanoparticles-dna.html>

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