Using self-assembly, scientists are coaxing nanoparticles into making new, customized materials

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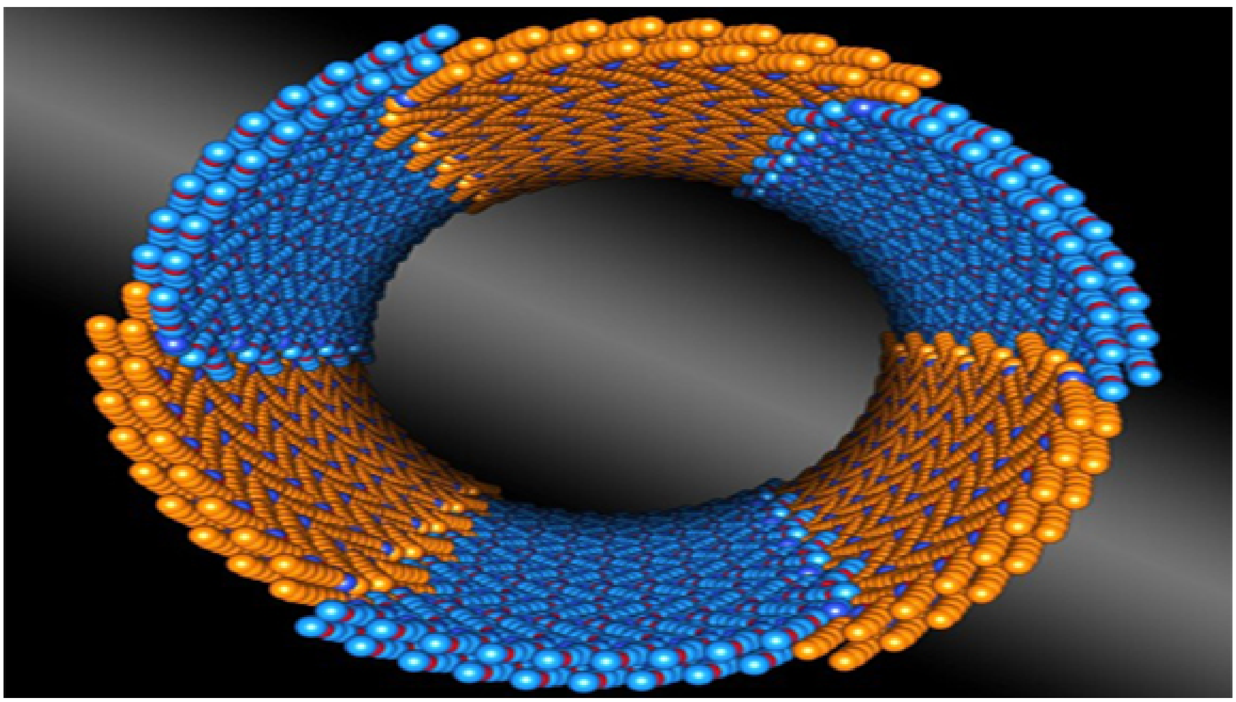


Scientists from DOE's Lawrence Berkeley National Laboratory discovered a family of synthetic polymers that self-assemble into nanotubes with consistent diameters. Credit: US Department of Energy

When you bring a box home from the furniture store, you don't expect the screws, slats, and other pieces to magically converge into a bed or table. Yet this self-assembly occurs every day in nature. Nothing tells atoms to link together; nothing tells DNA how to form. Living materials contain the very instructions and ability to become a larger whole.

"Self-assembly is the universal process by which very complex structures are put together in nature. They are dynamic, they are multi-functional, they are adaptable," said Nick Kotov, a University of Michigan researcher.

Unlocking self-assembly could allow us to create materials that don't exist naturally and we can't currently create ourselves.

Using self-assembly, scientists could create custom materials that are both versatile like biological systems and tough like industrial ones. These materials could be used in better water purifiers, more efficient solar cells, faster catalysts that improve manufacturing, and next-generation electronics. Using self-assembly in manufacturing could also lead to cheaper and more efficient processes.

"We want to make synthetic materials that rival what we see in nature," said Ron Zuckermann, a researcher at the Molecular Foundry, a Department of Energy (DOE) Office of Science user facility. "Biological systems are very sensitive and fragile. We want to make rugged industrial-grade materials that can do the same things [they do]."

But scientists can't create things that combine the best of both biological and synthetic characteristics out of just any substance. Nanoparticles are likely to be the key. When scientists assemble these tiny particles into sheets or tubes, the final product is often just one atom tall. Because of their size, nanoparticles act differently than large amounts of the same material. For example, a chunk of gold doesn't scatter light the way a diamond does. But gold nanoparticles scatter light very well, making them useful in electron microscopes. Unlike regular materials, scientists can control nanoparticles' characteristics by changing their size and shape.

Right now, industry can only use one type of nanoparticle at a time. That's what you see in sunscreen and fabrics that use nanoparticles. However, to build custom materials, scientists need to make multiple kinds of nanoparticles interact. Currently, the only way to do this is to construct these materials particle-by-particle. This is a very time-consuming process.

To expand nanoparticles' potential applications, the Department of Energy's Office of Science is supporting research to harness self-assembly. Because nanoparticles of metals or semiconductors won't self-assemble in the same ways as living systems do, scientists are examining their differences and similarities.

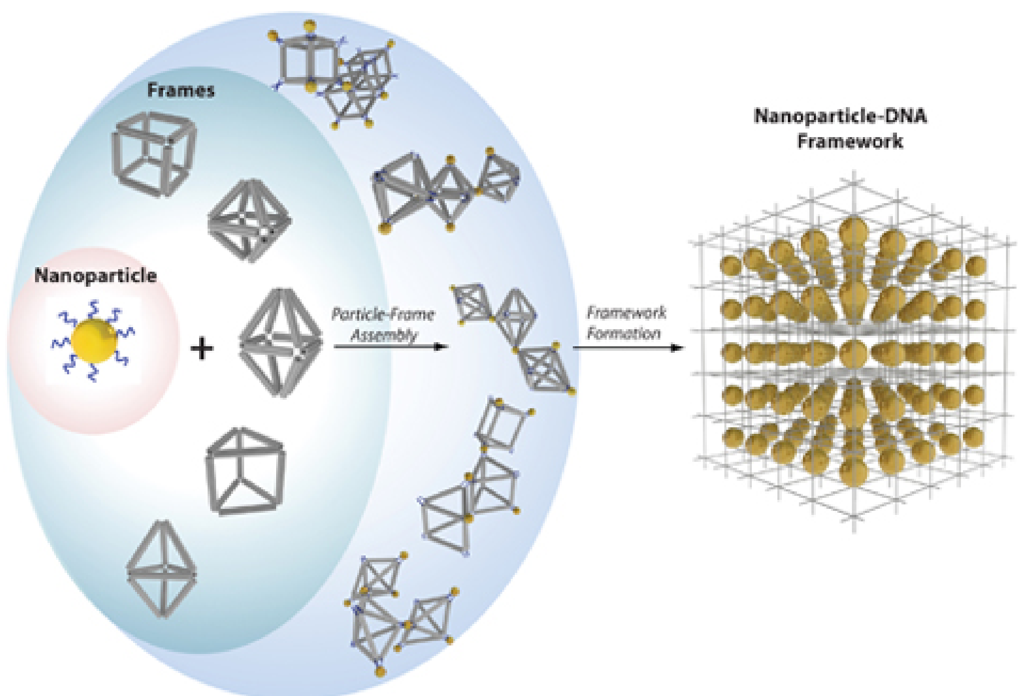
Spontaneous Construction

Some materials, scientists found, will self-assemble if you place them together in a liquid solution. They snap together as if by magic. But it's up to researchers to figure out which materials and solutions to mix together to give the shapes and characteristics they need.

Researchers at DOE's Lawrence Berkeley National Laboratory (LBNL) discovered a family of synthetic polymers that form hollow nanotubes when you put them in water. Nanotubes could improve catalysts, transport other nano-technology, and move antibiotics through the body. This discovery could also lead to making nanostructures that perform the huge number of functions that proteins do, but are sturdier and longer-lasting than proteins.

"I'm really excited by the ability to make protein-mimicking materials," said Zuckermann.

These nanotubes have two major advantages over previous ones. Scientists could manipulate them to have a consistent length and diameter. This is essential for building bigger structures with more practical applications. The hollow tubes also formed in a way that makes them less likely to collapse into a solid cylinder.



Researchers at DOE's Brookhaven National Laboratory have discovered how to combine DNA and nanoparticles so that the nanoparticles self-assemble into a variety of 3D structures. Credit: US Department of Energy

A similar effort at the University of Michigan found a form of cadmium sulfide, which is used to make solar panels, that self-assembles into shells in water that is moderately basic. Living systems use nanoshells for essential functions, such as controlling the location of chemical reactions. The synthetic shells, which are about half the diameter of a virus, could be used in gene therapy. The University of Michigan researchers modeled the shells at the DOE Office of Science's National Energy Research Scientific Computing Center user facility before they created them in the lab.

DNA and Tiny Diamonds: The Smallest Guides Imaginable

Unfortunately, spontaneous self-assembly relies heavily on the particles' characteristics. Use different particles, and self-assembly will either form different structures or not occur at all.

But researchers are looking into a different approach that will work no matter what type of particle they use. With this method, scientists attach a material that wants to self-assemble to a different nanomaterial that doesn't. The materials that want to self-assemble act like Velcro strips used to hang pictures. Normally, the pictures and wall wouldn't stick together. But by applying a Velcro strip to each one and pushing on them, they lock in place. With this method, scientists could connect any type of nanoparticles and do so in whatever form they wish.

DNA is one of the most promising forms of this nano-Velcro. Scientists at the Center for Functional Nanomaterials (CFN), a DOE Office of Science user facility at Brookhaven National Laboratory, are investigating this method.

"Using DNA, we can instruct particles how to connect to each other," said Oleg Gang, a CFN researcher and Columbia University professor. When scientists attach synthetic DNA to nanoparticles, the DNA strands pair up in the same way they do in every living thing, bringing the nanoparticles along.

"It's a 'smart' tool," said Fang Lu, a CFN researcher. "We can design what kind of bonding is attractive, what kind of bonding is repulsive."

In a 2015 study, scientists used the DNA to connect different types of nanoparticle shapes. While spheres would normally attach only to spheres, using DNA allowed them to also connect with blocks.

After that, researchers moved on to creating 3-D frames out of the DNA. This study took what they had learned about connecting different shapes together to the next level. First, the scientists placed a nanoparticle with a few single-stranded DNA hanging off of it into each corner of a synthetic DNA frame. These strands connected the particles, bringing together the particles and frames to form three-dimensional objects. By connecting frames that had a variety of shapes – cubes, octahedrons, and tetrahedra – scientists could form different 3-D architectures. This method could lead to materials industry could use for manipulating light, making chemical reactions faster, and influencing biological processes.

Now, scientists are using these frames to build customized 3-D nanoshapes. So far, they've been able to design zig-zags, stick figures, and other designs. By sticking a gold nanoparticle in the middle of each frame, they even created a crystal structure similar to that seen in diamonds. Scientists hope that by changing configurations and adding new types of particles, they can coax out even more characteristics.

At DOE's SLAC National Accelerator Laboratory, researchers are using tiny diamonds themselves. They discovered how to self-assemble "diamonoids" into the smallest nanowires ever made that are still stable enough to meet scientists' needs. Unlike smaller nanowires, scientists can store diamonoid ones in air without them breaking down or disperse them in solvents without changing their structure.

"The really shocking thing was that we got this beautiful three-atom cross-section of nanowires," said Nick Melosh, a SLAC researcher. In comparison, the smallest carbon nanowires are 10 atoms wide.

To make these nanowires, the scientists attached a sulfur atom to the molecular-scale diamond particles. When they placed this combination in a solution with copper ions, the sulfur latched onto the copper. This created the basic nanowire building block - a diamonoid cage carrying copper and sulfur atoms. The diamonoids in the separate blocks then drew together spontaneously, pulling the other nanoparticles along. This formed the nanowire.

The next big challenge is to use self-assembly to design materials that can solve specific problems, such as capturing the right type of light for solar cells, or filtering out microbes from water.

"[I want to] develop methods for creating systems that you have in your imagination. And that's very, very inspiring," said Gang.

Provided by US Department of Energy

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