Self-assembling system uses magnets to mimic specific binding in DNA

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Acrylic panels containing tiny magnets were glued onto flexible mylar strips, forming the basic building blocks for researchers to explore the potential of magnetically controlled self-assembling systems. Credit: Lindsay France/Cornell University

Sometimes it's best to let the magnets do all the work.

A team led by Cornell University physics professors Itai Cohen and Paul

McEuen is using the binding power of magnets to design self-assembling systems that potentially can be created in nanoscale form.

Their paper, "Magnetic Handshake Materials as A Scale-Invariant Platform for Programmed Self-Assembly," published Nov. 21 in *Proceedings of the National Academy of Sciences*.

To make small systems—such as miniature machines, gels and metamaterials—that essentially build themselves, the researchers took inspiration from DNA origami, in which atomic-scale DNA strands can be folded into two- and three-dimensional structures through a process called complementary base pairing, where specific nucleotides bind to one another: A to T and G to C.

Rather than relying on atomic bonds, the team was drawn to another form of attraction: magnetics. Here, the attraction and repulsion between multiple magnets can serve as a kind of intelligent connection, like a handshake. Magnetic interactions also make for strong, versatile bonds that aren't easily disrupted by thermal effects. With a large enough array of magnets in a variety of orientations, thousands of different configurations would be possible.

The researchers tested their design theory by making centimeter-sized acrylic panels, each containing four tiny magnets in a square pattern. This arrangement allowed them to make four unique magnetic interactions.

"By controlling the pattern of magnetic dipoles on each panel, we can essentially get lock-and-key binding," said Cohen. "And by gluing these panels onto a flexible mylar strip in designed sequences, we created our basic building blocks."

To activate the self-assembly, the separate strands were scattered on a shaker table, with the table's vibrations preventing the magnets from forming bonds. As the shaking amplitude was decreased, the magnets attached in their designated order and the strands formed the target structures.

The ultimate goal, says Cohen, is to produce nanoscale versions of these systems, with self-assembling units that are only a hundred nanometers in diameter, or a thousandth of a human hair in diameter.

"It is quite a broad platform with many applications that are very exciting and interesting," said postdoctoral researcher Ran Niu, the paper's lead author. "You can design a lot of structures. We can build optically active actuators. We can build functional machines that we can control."

The project was recently awarded a $1.1 million Designing Materials to Revolutionize and Engineer Our Future grant from the National Science Foundation, which will enable the team to further explore nanoscale incarnations.

"The part that really interests me is the idea of just how structure and information interact to make shape-changing machines," said senior co-author McEuen, the John A. Newman Professor of Physical Science and director of the Kavli Institute at Cornell for Nanoscale Science, where Cohen is a senior investigator. "So RNA, for example, is this incredibly amazing molecule in our bodies that has a lot of information in it, but also has all sorts of interesting functions. And so this is sort of an analog of that system, where we can begin to understand how you mix information and structure to get complex behavior."

While nanoscale machines and self-assembling systems are not new, this project marks the first time the two concepts have been combined with magnetic encoding.

"The vision is that one day I will simply hand you a magnetic disk, you put it into your hard drive, it writes all the magnetic codes that you designed, then you take it and put it in some acid to release the building blocks," Cohen said. "All the little strands with the magnetic patterns that we encoded would come together and self-assemble into some sort of machine that we could control using external magnetic fields."

"This work opens up the field of design," Cohen added. "We're now giving people who are interested in the mathematics of designing materials from scratch a tool set that is incredibly powerful. There's really no end to the creativity and potential for interesting designs to come out of that."

The potential learning opportunities can be found in the research team itself. The paper's co-authors include Edward Esposito, a former university staff member who audited Cohen's Electricity and Magnetism honors class and became a technician in Cohen's lab. He is now pursuing a Ph.D. at the University of Chicago. And co-author Jakin Ng is an Ithaca High School student who started working part time in Cohen's lab through the Learning Web youth experiential education program. Ng's knowledge of origami patterns helped the researchers design some of their structures.

More information: Ran Niu et al, Magnetic handshake materials as a scale-invariant platform for programmed self-assembly, *Proceedings of the National Academy of Sciences* (2019). DOI: 10.1073/pnas.1910332116

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