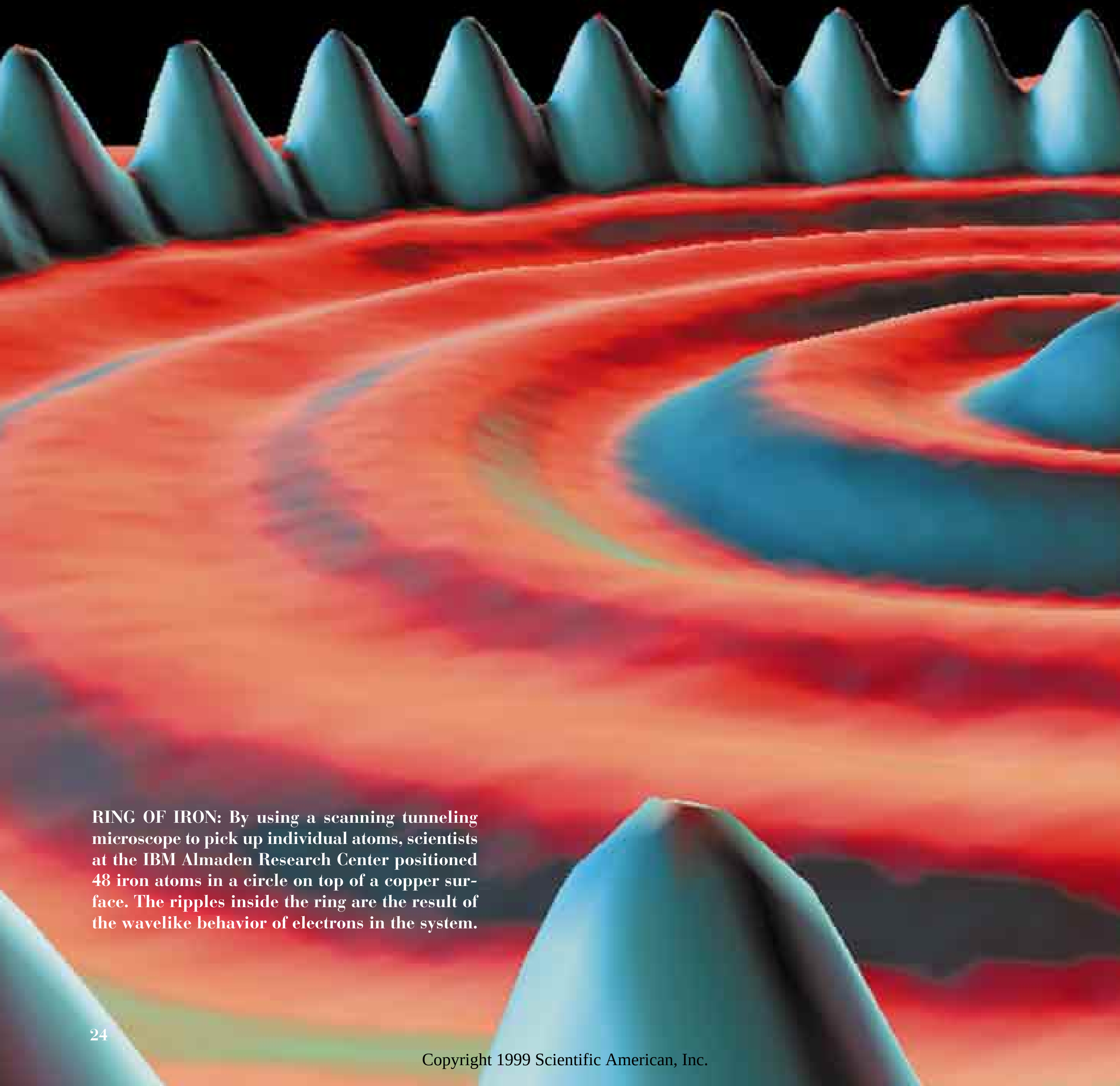
Some Assembly

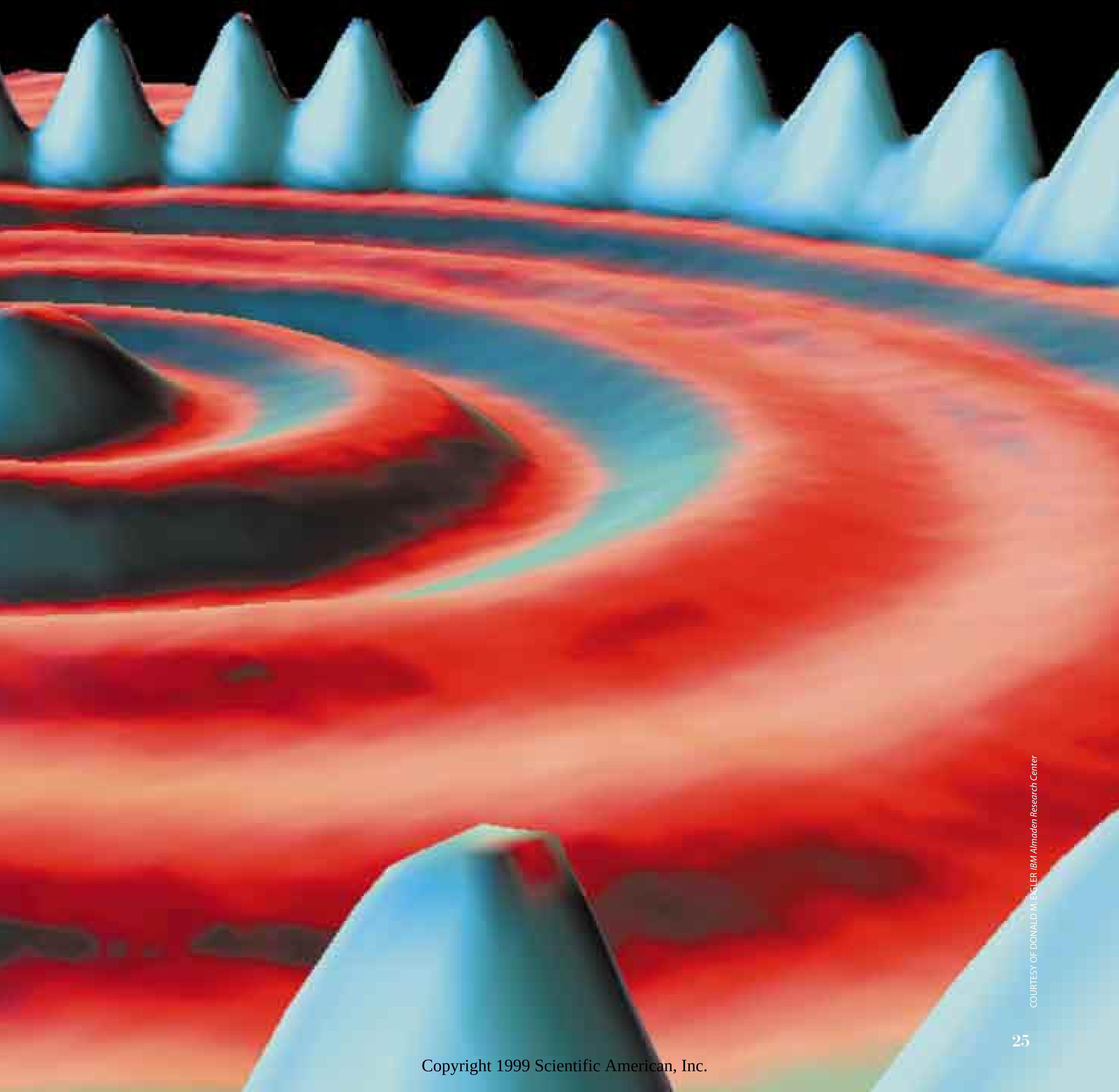
Scientists can now grab an individual atom and place it exactly where they want. Welcome to the new and exciting world of atomic engineering



RING OF IRON: By using a scanning tunneling microscope to pick up individual atoms, scientists at the IBM Almaden Research Center positioned 48 iron atoms in a circle on top of a copper surface. The ripples inside the ring are the result of the wavelike behavior of electrons in the system.

Required

by Sasha Nemecek



COURTESY OF DONALD M. EIGLER *IBM Almaden Research Center*

Everything around us—from concrete blocks to computer chips—is made of atoms. They are nature's Tinkertoy set, but it can take a Herculean effort for humans to rearrange individual, all but weightless, atoms. Consider how minuscule they are: some two trillion would fit in this letter A. But researchers have now developed tools that enable them to see, grasp and move these tiny particles.

The technology dates back to the early 1980s, when two European physicists, Gerd Binnig and Heinrich Rohrer, working at the IBM Research Laboratories in Zürich, built the first instrument that could display images of atoms: the scanning tunneling microscope, or STM.

Despite its name, though, the STM is not a true microscope. Rather than capturing direct images with the help of lenses, optics and light, an STM relies instead on translating electric current (from the surfaces of conductors—metals, semiconductors or superconductors) into images of atoms.

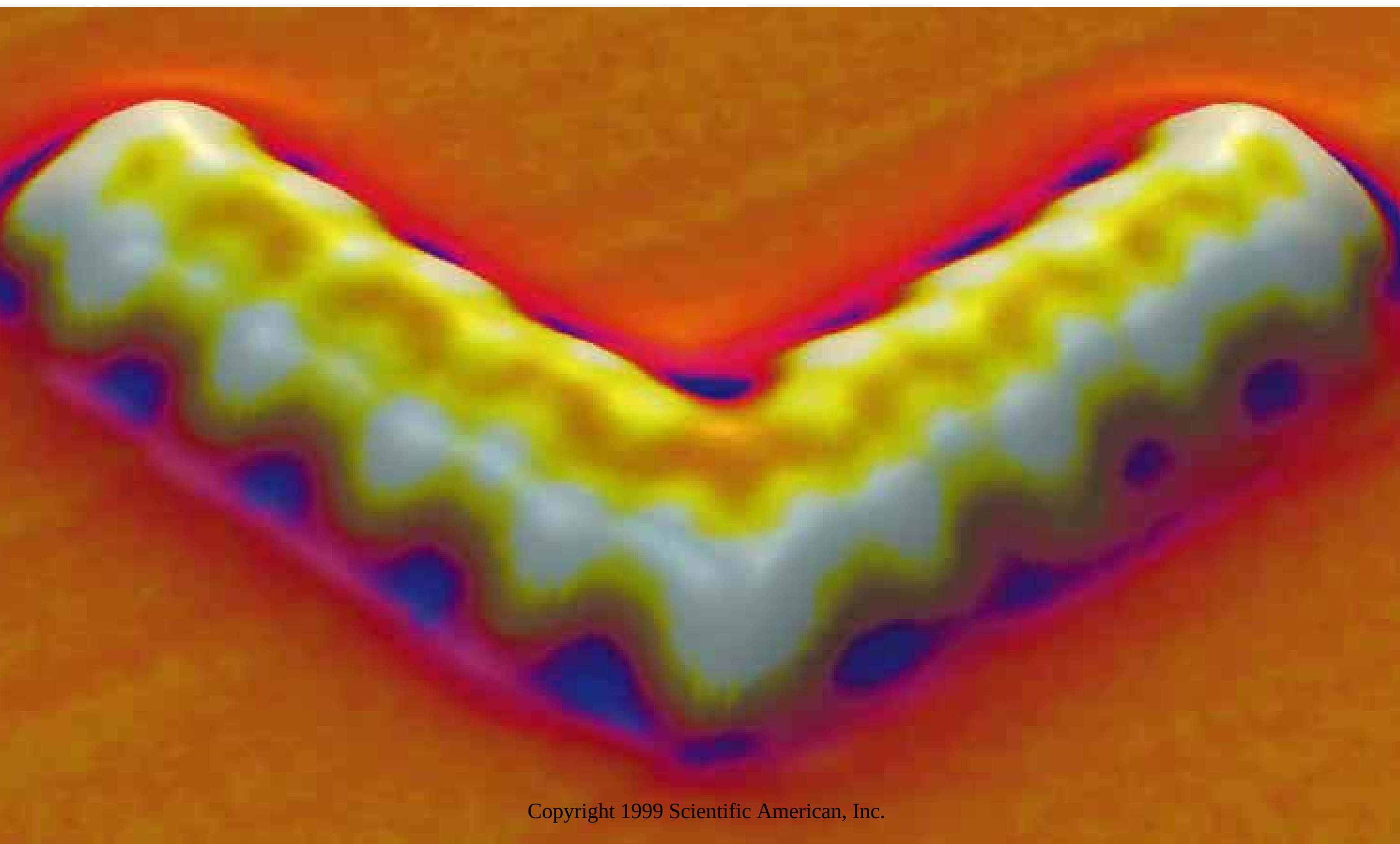
The most important feature of any STM is its ultrasharp probe—typically a thin wire designed so that a single atom hangs from the tip. Atoms consist of a positively charged nucleus at their center surrounded by negatively charged electrons, in what scientists call an electron cloud. In the case of atoms positioned at the surface of any material, these electron clouds protrude just slightly above the plane, like rows of tiny foothills. Once the STM probe comes close enough to one of the surface atoms—around a nanometer (one billionth of a meter) away—the electron cloud of the atom on the end of the probe and that of the surface atom begin to overlap, causing an electronic interaction. When a low voltage is applied to the STM tip, a so-called quantum tunneling current flows between the two electron clouds. This current turns out to be highly dependent on the distance between the tip and the surface.

A helpful way to think of the STM probe is like a finger reading Braille. Researchers using an STM typically program the computer controlling the probe to keep the current between the tip and the surface atoms at a constant level. So as the feedback probe scans back and forth across a sample, it also shifts up and down, following the contours of the electron clouds. For instance, as an electron cloud emerges from the plane of the surface and the tip comes closer to the atom, the tunneling current at the probe would ordinarily increase. As soon as the computer registers this difference, however, it tells the tip to pull back from the surface and in this way maintains a stable current reading.

Alternatively, as the electron cloud falls below the surface plane and the tip separates from the atom, the probe would normally detect a lower tunneling current. Once again, though, the probe responds to this change, coming closer to the surface to preserve a constant current

COURTESY OF DONALD M. EIGLER *IBM Almaden Research Center*

MIX-AND-MATCH MOLECULE: Atomic engineers eventually hope to create molecules from scratch, adding atoms exactly as needed to perform specific functions. This molecule, with 18 cesium and 18 iodine atoms, was built—one atom at a time—with a scanning tunneling microscope (or STM).



THE HOLY GRAIL FOR THESE ATOMIC ENGINEERS IS TO BUILD A MOLECULE ATOM BY ATOM.

level. Over time the probe generates a topographical survey of the surface, essentially "feeling" the size and location of atoms.

The results of STM scans can be stunning. Scientists use computer programs to translate the probe's motion into images of the surprisingly rugged terrain of seemingly smooth surfaces, often adding color to emphasize the peaks and valleys of the atomic geography. Indeed, early work with the STM centered on generating images of the atoms at the surface of metals, semiconductors and superconductors, revealing unexpected and often informative patterns and imperfections.

More recently researchers have discovered they can also use the STM to move individual atoms. Instead of just hovering right above the atoms, the STM tip can actually reach down and pick up a single atom. This trick is possible because the interaction between the atom on the probe's tip and the surface atom becomes stronger as the tip moves closer to the surface. Eventually this interaction leads to a temporary chemical bond between the two atoms, which is stronger than those between the surface atom and its neighbors. Once this bond forms, the tip essentially holds on to the surface atom, permitting scientists to move the probe and its guest to the desired location.

COURTESY OF HONGJIE DAI *Stanford University*

SHORT LIST: A carbon nanotube—essentially a "buckyball" stretched into a hollow tube of carbon atoms some 10 nanometers wide—has been transformed into a writing implement. Using an atomic force microscope with a nanotube tip, researchers at Stanford University removed hydrogen atoms from the top of a silicon base. The exposed silicon oxidized, leaving behind a visible tracing.

Today the technology behind the STM has been adapted for use in a variety of similar imaging devices. The atomic force microscope, or AFM, for instance, enables scientists to study biological systems, from DNA to molecular activity within a cell. Instead of relying on changes in the quantum tunneling current between the tip and surface atoms, the AFM exploits fluctuations in other types of atomic and molecular scale forces—mechanical or electrostatic forces, for instance—again feeling the surface geography. AFM has become a significant tool for biologists and chemists.

The holy grail for these atomic engineers is to build a molecule atom by atom, with the goal of one day constructing a new type of material. Physicist Donald M. Eigler, who works at the IBM Almaden Research Center in San Jose, has produced in his laboratory a molecule consisting of 18 cesium and 18 iodine atoms [*see STM image on opposite page*]—the largest molecule ever to be assembled in atomic installments. And although there is no immediate use for such a compound, there is plenty of interest in the technology. The dream is to build new materials that might serve, say, as ultrahigh-density data storage for future computers or as a novel medical device. All of this with a few atomic Tinkertoys. SA

About the Author

SASHA NEMECEK is co-editor of this issue of *Scientific American Presents*. She wrote this article with her own nanopencil.