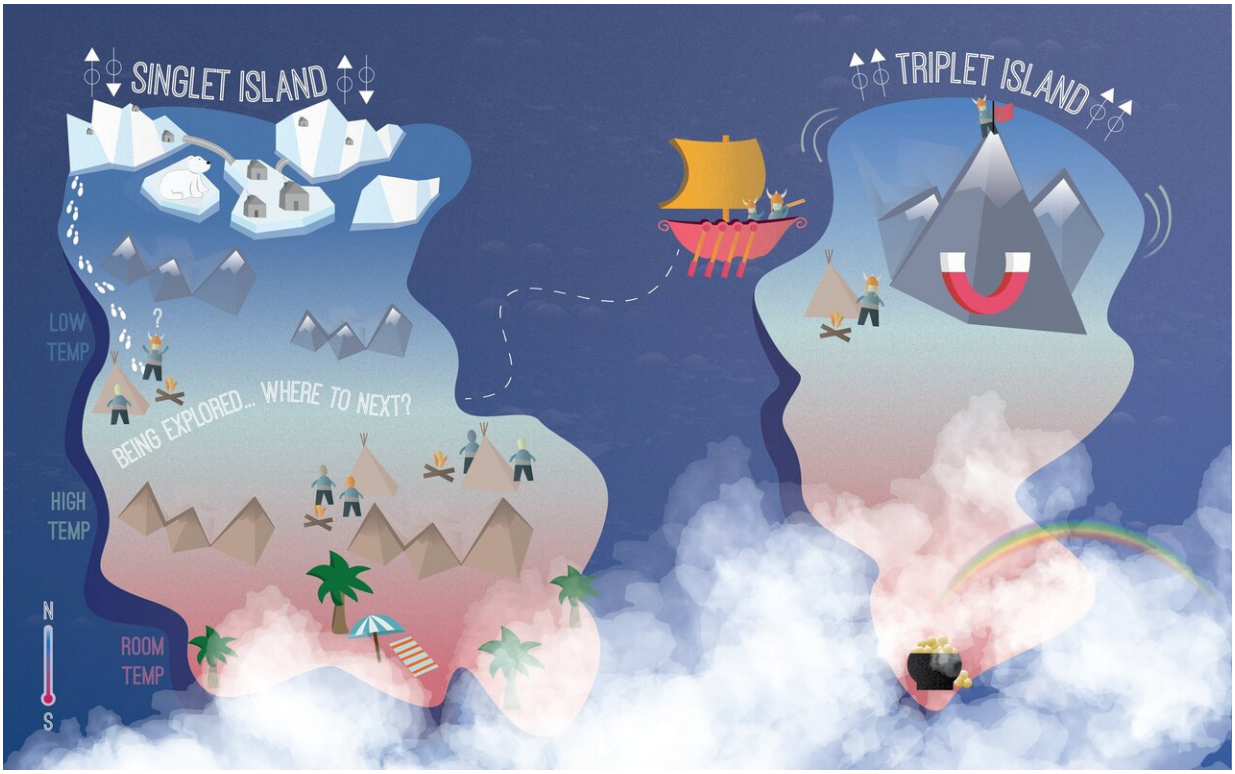
Newfound superconductor material could be the 'silicon of quantum computers'

August 15 2019



We have already found lots of superconductors, but this whimsical illustration shows why one superconductor's newfound properties may make it especially useful. Most known superconductors are spin singlets, found on the island to the left. Uranium ditelluride, however, is a rare spin triplet, found on the island to the right, and also exists at the top of a mountain representing its unusually high resistance to magnetic fields. These properties may make it a good material for making qubits, which could maintain coherence in a quantum computer despite interference from the surrounding environment. Credit: Natasha Hanacek/NIST

A potentially useful material for building quantum computers has been unearthed at the National Institute of Standards and Technology (NIST), whose scientists have found a superconductor that could sidestep one of the primary obstacles standing in the way of effective quantum logic circuits.

Newly discovered properties in the compound uranium ditelluride, or UTe_2, show that it could prove highly resistant to one of the nemeses of quantum computer development—the difficulty with making such a computer's memory storage switches, called qubits, function long enough to finish a computation before losing the delicate physical relationship that allows them to operate as a group. This relationship, called quantum coherence, is hard to maintain because of disturbances from the surrounding world.

The compound's unusual and strong resistance to magnetic fields makes it a rare bird among superconducting (SC) materials, which offer distinct advantages for qubit design, chiefly their resistance to the errors that can easily creep into quantum computation. UTe_2's exceptional behaviors could make it attractive to the nascent quantum computer industry, according to the research team's Nick Butch.

"This is potentially the silicon of the quantum information age," said Butch, a physicist at the NIST Center for Neutron Research (NCNR). "You could use uranium ditelluride to build the qubits of an efficient quantum computer."

Research results from the team, which also includes scientists from the University of Maryland and Ames Laboratory, appear today in the journal *Science*. Their paper details UTe_2's uncommon properties, which are interesting from the perspectives of both technological application and fundamental science.

One of these is the unusual way the electrons that conduct electricity through UTe_2 partner up. In copper wire or some other ordinary conductor, electrons travel as individual particles, but in all SCs they form what are called Cooper pairs. The electromagnetic interactions that cause these pairings are responsible for the material's superconductivity. The explanation for this kind of superconductivity is named BCS theory after the three scientists who uncovered the pairings (and shared the Nobel Prize for doing so).

What's specifically important to this Cooper pairing is a property that all electrons have. Known as quantum "spin," it makes electrons behave as if they each have a little bar magnet running through them. In most SCs, the paired electrons have their quantum spins oriented in a single way—one electron's points upward, while its partner points down. This opposed pairing is called a spin singlet.

A small number of known superconductors, though, are nonconformists, and UTe_2 looks to be among them. Their Cooper pairs can have their spins oriented in one of three combinations, making them spin triplets. These combinations allow for the Cooper-pair spins to be oriented in parallel rather than in opposition. Most spin-triplet SCs are predicted to be "topological" SCs as well, with a highly useful property in which the superconductivity would occur on the surface of the material and would remain superconducting even in the face of external disturbances.

"These parallel spin pairs could help the computer remain functional," Butch said. "It can't spontaneously crash because of quantum fluctuations."

All quantum computers up until this point have needed a way to correct the errors that creep in from their surroundings. SCs have long been understood to have general advantages as the basis for quantum computer components, and several recent commercial advances in

quantum computer development have involved circuits made from superconductors. A topological SC's properties—which a quantum computer might employ—would have the added advantage of not needing quantum error correction.

"We want a topological SC because it would give you error-free qubits. They could have very long lifetimes," Butch said. "Topological SCs are an alternate route to quantum computing because they would protect the qubit from the environment."

The team stumbled upon UTe_2 while exploring uranium-based magnets, whose electronic properties can be tuned as desired by changing their chemistry, pressure or magnetic field—a useful feature to have when you want customizable materials. (None of these parameters are based on radioactivity. The material contains "depleted uranium," which is only slightly radioactive. Qubits made from UTe_2 would be tiny, and they could easily be shielded from their environment by the rest of the computer.)

The team did not expect the compound to possess the properties they discovered.

"UTe_2 had first been created back in the 1970s, and even fairly recent research articles described it as unremarkable," Butch said. "We happened to make some UTe_2 while we were synthesizing related materials, so we tested it at lower temperatures to see if perhaps some phenomenon might have been overlooked. We quickly realized that we had something very special on our hands."

The NIST team started exploring UTe_2 with specialized tools at both the NCNR and the University of Maryland. They saw that it became superconducting at low temperatures (below -271.5 degrees Celsius, or 1.6 kelvin). Its superconducting properties resembled those of rare

superconductors that are also simultaneously ferromagnetic—acting like low-temperature permanent magnets. Yet, curiously, UTe_2 is itself not ferromagnetic.

"That makes UTe_2 fundamentally new for that reason alone," Butch said.

It is also highly resistant to magnetic fields. Typically a field will destroy superconductivity, but depending on the direction in which the field is applied, UTe_2 can withstand fields as high as 35 tesla. This is 3,500 times as strong as a typical refrigerator magnet, and many times more than most low-temperature topological SCs can endure.

While the team has not yet proved conclusively that UTe_2 is a topological SC, Butch says this unusual resistance to strong magnetic fields means that it must be a spin-triplet SC, and therefore it is likely a topological SC as well. This resistance also might help scientists understand the nature of UTe_2 and perhaps superconductivity itself.

"Exploring it further might give us insight into what stabilizes these parallel-spin SCs," he said. "A major goal of SC research is to be able to understand superconductivity well enough that we know where to look for undiscovered SC materials. Right now we can't do that. What about them is essential? We are hoping this material will tell us more."

The study is published in the journal *Science*.

More information: "Nearly ferromagnetic spin-triplet superconductivity" *Science*, science.sciencemag.org/cgi/doi … 1126/science.aav8645

Provided by National Institute of Standards and Technology