Physicists unveil unexpected properties in superconducting material

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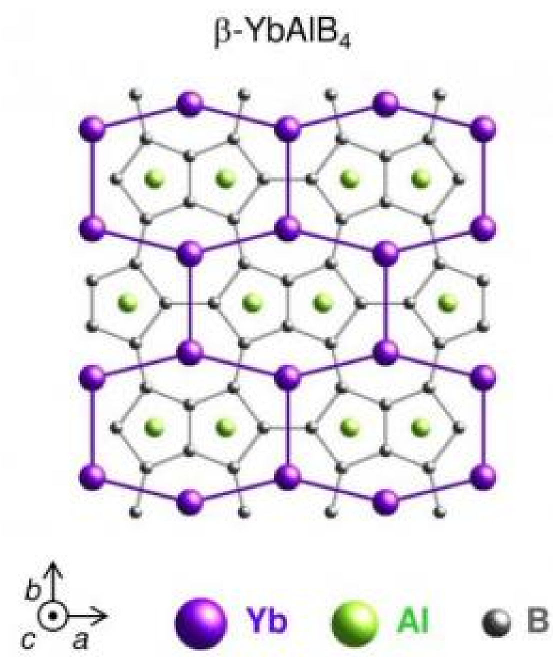

An exotic new superconductor based on the element ytterbium displays unusual properties that could change how scientists understand and create materials for superconductors and electronics. In a paper published Jan. 21 in the journal Science, University of Tokyo and Rutgers University researchers report that this material, beta-YbAlB4, can reach a point where seemingly contradictory electrical and magnetic properties coexist, without being subject to massive changes in pressure, magnetic fields, or chemical impurities. This point, which physicists call "quantum critical," often defines whether and how a material can become superconducting -- a valued property where all resistance to electrical flow vanishes. Courtesy Science/AAAS

In 2008, an international team of scientists studying an exotic new superconductor based on the element ytterbium reported that it displays unusual properties that could change how scientists understand and create materials for superconductors and the electronics used in computing and data storage.

But a key characteristic that explains the material's unusual properties remained tantalizingly out of reach in spite of the scientists' rigorous battery of experiments and exacting measurements. So members of that team from the University of Tokyo reached out to theoretical physicists at Rutgers University to help uncover the material's secrets.

In a paper published Jan. 21 in the journal Science, the Tokyo and Rutgers researchers now report that the material can reach a point where seemingly contradictory electrical and magnetic properties coexist, without being subject to massive changes in pressure, magnetic fields, or chemical impurities.

This point, which physicists call "quantum critical," often defines whether and how a material can become superconducting – a valued property where all resistance to electrical flow vanishes. Superconductivity, discovered 100 years ago, has since been put to work in a variety of applications, from physics research to medical MRI scanners.

Scientists have long been able to "tune" materials toward quantum criticality by altering the materials' properties. This is done by exposing them to high magnetic fields and pressures, or by adding certain atomic impurities to the materials. The material studied by the Tokyo and Rutgers researchers, however, appears to be the first to exhibit quantum criticality in its natural state, without tuning.

"This is a completely unexpected result," said Piers Coleman, professor of physics and astronomy, School of Arts and Sciences, at Rutgers. "It could be the first example of what physicists describe as a 'strange' metallic phase of matter, manifesting itself intrinsically, without any tuning of the material's properties."

The material synthesized and studied by the Japanese experimental physicists is an exotic crystal made up of the elements ytterbium, boron, and aluminum. It has the chemical formula $YbAlB_4$ but the physicists gave it the nickname "YBAL" (pronounced "why-ball"). Superconductivity had earlier been observed in YBAL, in a particular crystalline form called the "beta" structure. The Tokyo physicists suspected they could find a quantum critical point in the material; however, its superconducting behavior that kicks in slightly above absolute zero masked their ability to pinpoint it.

Coleman and postdoctoral researcher Andriy Nevidomskyy examined the data from the Tokyo experiments at a wide range of temperatures and magnetic field strengths. All the data, they found, collapsed onto a curve that pointed to the unobservable quantum critical point (QCP) hidden by the superconducting phase. The QCP was within hair's breadth of zero magnetic field, with no externally applied tuning of pressure or other parameters.

"It's kind of a dream system," said Coleman, also a member of the Rutgers Center for Materials Theory. "We've found a material that is intrinsically quantum critical with very simple behavior. It's puzzling, because there's nothing simple about the material's structure. We're not sure why this happens."

Nevidomskyy, now an assistant professor of physics and astronomy at Rice University, likened the discovery of the QCP to finding a black hole in outer space.

"You can't see a black hole because light can't escape from its grip; however, you can observe the gravitational pull that a black hole has on nearby stars," he said. "Similarly, we couldn't see the quantum critical point directly, but we could see evidence of it in the material's magnetic properties and thereby deduce its position underneath the veil of superconductivity."

The discovery that most intrigues the physicists is that beta-YBAL could be revealing an exotic new phase of matter known as the "critical strange metal" phase. At the quantum critical point, the material can shift between conventional electrical behavior, which physicists call a Fermi liquid, to superconducting behavior, and to a condition that resembles neither, called "strange metal" behavior. This behavior has been observed in superconducting materials, but it's not known whether it occurs only in the vicinity of a QCP or whether it can exist over an extended range of physical conditions, which would essentially make it a phase of matter.

Proposed by Nobel laureate Philip Anderson, the idea of strange metal phases has been long debated by physicists. "It is extremely controversial," said Coleman. "The experiments our Tokyo colleagues are doing right now might provide more evidence. It could change our basic understanding of materials going forward."

"We are very excited," said Satoru Nakatsuji, professor and leader of the Tokyo research team. "If true, this would be an amazing discovery, opening new horizons in our understanding of quantum criticality."

Coleman praised the working relationship that he and Nevidomskyy have with Nakatsuji's team, including the paper's primary author, Yosuke Matsumoto, and five other researchers: K. Kuga, Y. Karaki, N. Horie, Y. Shimura, and T. Sakakibara. The physicists are affiliated with the University of Tokyo's Institute for Solid State Physics in Kashiwa, Japan.

"In modern science, this interplay between theory and experiment is extremely important," Coleman said. "If you can get a powerful current of ideas going, you can take physics much further. A lot of our work has been done by video conference. Unfortunately with the time difference, it means one of our groups had to get up early while the other had to stay late at night."

Provided by Rutgers University

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