Scientists launch quest to develop quantum sensors for probing quantum materials

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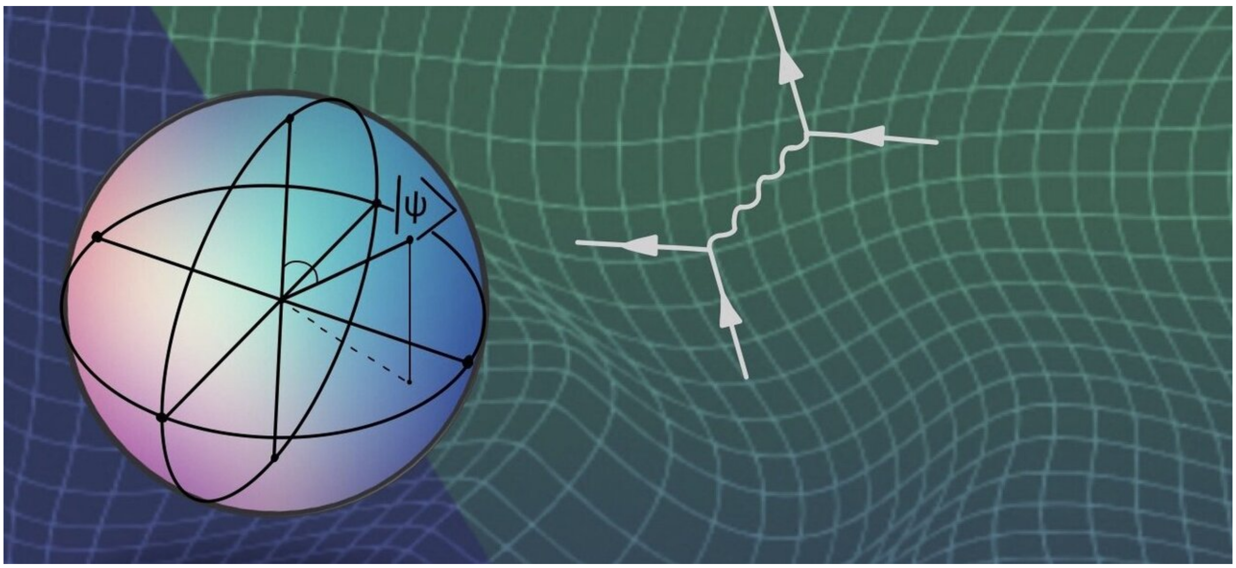

When it comes to fully understanding the hidden secrets of quantum materials, it takes one to know one, scientists say: Only tools that also operate on quantum principles can get us there.A new Department of Energy research center will focus on developing those tools. Based at the University of Illinois at Urbana-Champaign, the Center for Quantum Sensing and Quantum Materials brings together experts from UIUC, DOE's SLAC National Accelerator Laboratory, Stanford University and the University of Illinois-Chicago. Credit: Caitlin Kengle/UIUC

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A new Department of Energy research center will focus on developing those tools. Based at the University of Illinois at Urbana-Champaign, the Center for Quantum Sensing and Quantum Materials brings together experts from UIUC, DOE's SLAC National Accelerator Laboratory, Stanford University and the University of Illinois-Chicago.

They'll work on developing three cutting-edge quantum sensing devices: a scanning qubit microscope, a spectroscopy instrument that takes advantage of pairs of entangled electrons and another instrument that will probe materials with pairs of photons from SLAC's X-ray free-electron laser, the Linac Coherent Light Source, which has recently reopened after an upgrade.

These new techniques will allow researchers to see in much greater detail why quantum materials do the weird things they do, paving the way to discovering new quantum materials and inventing even more sensitive probes of their behavior.

The work will focus on understanding the atomic-level processes behind unconventional superconductors that conduct electricity with no resistance at relatively high temperatures; topological insulators, which carry current with no loss along their edges; and strange metals, which superconduct when chilled but have strange properties at higher temperatures.

"What is exciting is that this center gives us a chance to create some really new quantum measurement techniques for studying energy-relevant quantum materials," center Director Peter Abbamonte, a professor of physics at UIUC, said in a press release.

"We often get trapped in the cycle of using the same old measurements—not because we don't need new kinds of information or knowledge, but because developing techniques is expensive and time consuming," Abbamonte said. The new center, he said, will allow scientists to push the envelope of quantum measurement by tackling bigger problems.

Exotic entangled states

Quantum materials get their name from the fact that their exotic properties stem from the cooperative behavior of electrons and other phenomena that obey the rules of quantum mechanics, rather than the familiar Newtonian laws of physics that govern our everyday world. These materials could eventually have a huge impact on future energy technologies—for instance, by allowing people to transmit power with essentially no loss over long distances and making transportation much more energy efficient.

But a quantum material may contain a confounding mixture of exotic, overlapping states of matter that are hard to sort out with conventional tools.

"In the quantum world everything becomes entangled, so the boundaries of one object start to overlap with the boundaries of another," said SLAC Professor Thomas Devereaux, one of six SLAC and Stanford researchers collaborating in the new center. "We'll be probing this entanglement using various tools and techniques."

Quantum sensors are nothing new. They include superconducting quantum interference devices, or SQUIDs, invented half a century ago to detect extremely small magnetic fields, and superconducting transition edge sensors, which incorporate SQUIDS to detect exquisitely small signals in astronomy, nuclear non-proliferation, materials analysis and homeland defense.

At a basic level, they operate by putting the sensor into a known quantum state and allowing it to interact with the object of interest. The interaction changes the state of the quantum system, and measuring the new state of the system reveals information about the object that could not be obtained with conventional approaches.

Qubits on a tip

In one of the technologies under development, the scanning qubit microscope, the quantum sensor would consist of one or more qubits placed on the tip of a probe and moved over the surface of a material. A qubit is a basic unit of quantum information, like the bits of ordinary computer memory that flip back and forth between zero and 1. But a qubit exists as a superposition of both zero and 1 states at once. The scanner's qubit might consist of a single hydrogen atom, for instance, with the spin of its single electron simultaneously existing as up, down and all possible states in between.

"You can try to entangle the qubit sensor with the quantum state of the material you're studying so you can actually sense the entanglement of quantum states within the material," said Kathryn Moler, Stanford's vice provost and dean of research. "If we can do that, it will be really cool."

Provided by SLAC National Accelerator Laboratory

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