UC SANTA BARBARA
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# Quantum Computing Research Edges Toward Practicality in UCSB Physics Laboratory

An important step –– one that is essential to the ultimate construction of a quantum computer –– was taken for the first time by physicists at UC Santa Barbara. The discovery is published in the current issue of the journal Nature.

The research involves the entanglement of three quantum bits of information, or qubits. Before now, entanglement research in the solid state has only been developed with two qubits. The UCSB finding comes from a collaboration of the research groups of physicists Andrew Cleland and John Martinis. Graduate student Matthew Neeley is the first author on the Nature paper. Meanwhile, a research group at Yale reported the same result.

"These entangled states are interesting in their own right, but they are also very important from the perspective of the larger, long-term goal of creating a quantum computer with many qubits," said Neeley.

The Cleland-Martinis group is studying superconducting quantum circuits and their potential uses in quantum computing. Quantum circuits are fabricated on microchips using techniques similar to those used in making conventional computers. When cooled to very low temperatures –– just a few hundredths of a degree above absolute zero –– they become superconducting and exhibit quantum effects.

Essentially behaving like artificial atoms, they can be manipulated and measured using electrical signals. Unlike atoms, however, these circuits can be designed to have only the properties that the scientists desire for various experiments –– providing a tool for exploring many of the fundamental aspects of quantum mechanics.

The simplest type of quantum system is one with just two possible states, known as a quantum bits by analogy with the classical bits that are the fundamental elements of conventional computers. UCSB's team uses quantum circuits of a type known as phase qubits, designed to behave as two-levels quantum systems. In this most recent work, the team fabricated and operated a device with three coupled phase qubits, using them to produce entangled quantum states.

"Entanglement is one of the strangest and most counterintuitive features of quantum mechanics," said Neeley. "It is a property of certain kinds of quantum states in which different parts of the system are strongly correlated with each other. This is often discussed in the context of bipartite systems with just two components. However, when one considers tripartite or larger quantum systems, the physics of entanglement becomes even richer and more interesting."

In this work, the team produced entangled states of three qubits. Neeley explained that unlike the two-qubit case, three qubits can be entangled in two fundamentally different ways, exemplified by a state known as GHZ, and another state known as W. The GHZ state is highly entangled but fragile, and measuring just one of the qubits collapses the other two into an unentangled state.

"The W state is in a certain sense less entangled, but nevertheless more robustly so –– two thirds of the time, measuring one qubit will still leave the other two in an entangled state," Neeley said. "We produced both of these states with our phase qubits, and measured their fidelity compared to the theoretical ideal states. Experimentally, the fidelity is never perfect, but we showed that it is high enough to prove that the three qubits are entangled."

"Entanglement is a resource that gives quantum computers an advantage over classical computers, and so producing multipartite entanglement is an important step for any system with which we might hope to construct a quantum computer," said Neeley.

The same result was published simultaneously, based on similar research from the group of Rob Schoelkopf, a physics professor at Yale. Both results are the first work showing three coupled superconducting qubits. This is a significant step toward scaling to increasingly larger numbers of qubits.

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## About UC Santa Barbara

The University of California, Santa Barbara is a leading research institution that also provides a comprehensive liberal arts learning experience. Our academic community of faculty, students, and staff is characterized by a culture of interdisciplinary collaboration that is responsive to the needs of our multicultural and global society. All of this takes place within a living and learning environment like no other, as we draw inspiration from the beauty and resources of our extraordinary location at the edge of the Pacific Ocean.