What's Next for Qubits?

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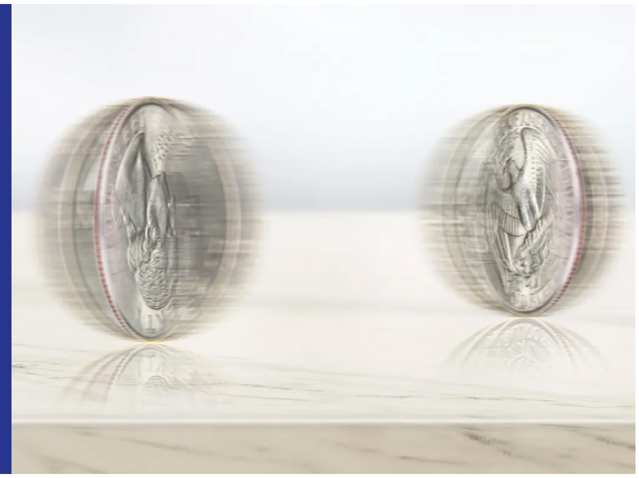

Next-gen schemes could help quantum leap forward.

"Quantum computers are not just faster, bigger computers," says Los Alamos quantum materials scientist Ray Newell. "They are fundamentally different."

Quantum computing is a fast-moving and exciting fledgling industry that will help solve problems that cannot be solved using classical approaches. Quantum computers won't be your next personal laptop, but they might help scientists develop superior cybersecurity and encryption or discover new materials, chemicals, or medicines. With this vast potential in mind, researchers worldwide, including at Los Alamos, are working all the angles—from novel materials for fast electronics to defining what sorts of problems are best suited for quantum computing—to help bring about the scientific innovations needed for quantum computing to coalesce as an industry.

One of those angles is the exploration of different types of qubits. A qubit is the fundamental unit at the heart of quantum computing, the quantum version of a bit. There are many different types of qubits, but all have two essential characteristics: First, qubits must be able to exist in a superposition of two logical states. Second, qubits should be able to be contained and manipulated, so as not to be influenced by each other or their environment, unless desired. One way of thinking about qubits is to imagine two coins simultaneously spinning on a table. While spinning, each has the potential to fall on either heads or tails—they are as if in a superposition of two states at once. Plus, the coins' movement across the table gives each the potential to interfere with the other, impacting its trajectory, spin, or even its heads-or-tails result.

Each type of qubit has different advantages and disadvantages. "There are some qubits that work reasonably well in that they hold quantum information uncorrupted for long periods of time and they can be reliably manipulated," explains Vivien Zapf, Los Alamos physicist and deputy director of the Department of Energy's Quantum Science Center. "Other qubits are better suited to quickly scaling to large numbers, but they have higher error rates. We need qubits at the sweet spot of being able to do both of those things. Los Alamos researchers are looking at the underlying science to help address these fundamental problems that plague existing quantum computers. This will lead to the next generation of qubits."

An example of the first kind, which work well but have scaling challenges, is a trapped-ion qubit. These are ionized atoms, so they are charged, which means they naturally interact with each other with very high fidelity. This is great for entanglement—the way that qubits relate to one another when strung together in a system—but it also means that after a certain number of trapped ions, right now about 30, the addition of just one more can cause them all to jumble together in a problematic way. Current estimates say about a million qubits would be needed for a general-purpose quantum computer to do anything meaningful, so, 30 down and 999,970 to go.

An example of the second kind of qubit described by Zapf, the kind that scale better but are more error prone, is a neutral-atom qubit. These are not charged, so they don't have the same jumbling problem, and presently the record is about 1000 (just 999,000 to go). Strontium and rubidium are both being explored at the Lab as neutral atom qubits. They are trapped in a laser-generated field of light called an optical tweezer, and as long as there is enough laser power to maintain the tweezer effect, adding more qubits has no negative effect on the system. Thanks to work on quantum algorithms, the error-rate problem for neutral-atom qubits is going down too, so trapped-ion qubits have recently catapulted to the forefront as a leading approach to quantum computing—perhaps filling that sweet spot between scalability and accuracy.

And, just to add a wrinkle, some next-gen qubits aren't qubits at all. One approach, called continuous variable quantum computation, uses physical observables that exist on a continuous scale, so they aren't finite. Another approach uses qudits—atom-based qubits that have, instead of two logical states, as many as 10 (or maybe more!). A qudit is sort of like a cross between a qubit and a continuous variable; it has more than two states but it's still finite.

"Los Alamos is a research and thought leader in all aspects of quantum technologies," says physicist Mike Martin of the Lab's experimental quantum group within the Materials Physics and Applications Division. "We are continually looking for breakthrough approaches for next-gen systems that might open up the field. We really are asking ourselves, all the time, 'What's next for qubits?'"