SCIENCE : PHYSICS : TECH : NANO : NEWS

Single spinning nuclei in diamond offer a stable quantum computing building block

At room temperature, carbon-13 nuclei in diamond create stable, controllable quantum register

Surmounting several distinct hurdles to quantum computing, physicists at Harvard University have found that individual carbon-13 atoms in a diamond lattice can be manipulated with extraordinary precision to create stable quantum mechanical memory and a small quantum processor, also known as a quantum register, operating at room temperature. The finding brings the futuristic technology of quantum information systems into the realm of solid-state materials under ordinary conditions.

The results, described this week in Science, could revolutionize scientists' approach to quantum computing, which is built on the profound eccentricity of quantum mechanics and could someday far outperform conventional supercomputers in solving certain problems.

"These experiments lay the groundwork for development of a new approach to quantum information systems," says Mikhail D. Lukin, professor of physics in Harvard's Faculty of Arts and Sciences.

Earlier advances in quantum computing have occurred inside high vacuums cooled to fractions of a degree above absolute zero. Individual quantum bits, or qubits -- the building blocks of a quantum computer, encoding information much as a conventional computer bit stores information as zeroes and ones -- are extremely fragile. Usually they decay very rapidly, losing quantum information within a tiny fraction of a second unless the qubit is suspended in high vacuum under these specialized, extreme conditions. This short "coherence time" has been a major impediment to advances in quantum computing.

Quantum mechanics dictates that coherence is destroyed -- and quantum information lost -- through contact with virtually anything, which is why previous attempts at quantum computing have occurred under such extreme circumstances. This need for absolute isolation has vexed scientists for more than a decade, not only because it is difficult to achieve experimentally -- not to mention in a practical computer -- but because it has complicated the ability to manipulate a quantum computer's input or read its output.

The new advance makes use of spinning properties of atomic nuclei, fundamental building blocks of matter with sub-nanometer dimensions, to encode quantum bits. Acting as tiny magnets, such nuclear spins are well known for their exceptional stability. But in practice the very weak interactions of nuclear spins with their surroundings -- the very reason for their near-perfect isolation -- means that it is essentially impossible to address and manipulate individual nuclei, and harder still to control interactions between them. For instance, many billions of nuclei are required in conventional MRI machines, which work by detecting signals from spinning nuclei.

"The problem is, what makes single nuclear spin so stable -- its weak interaction with its surroundings -- also prevents us from directly manipulating it," Lukin says. "How do you control something that can't interact with anything""

You do it gingerly and indirectly, the Harvard physicists report in Science. They found that nuclear spins associated with single atoms of carbon-13 -- which make up some 1.1 percent of natural diamond -- can be manipulated via a nearby single electron whose own spin can be controlled with optical and microwave radiation. The excitation of an electron by focusing laser light on a nitrogen vacancy center, a stable defect in a diamond lattice where nitrogen replaces an atom of carbon and develops an electronic spin in its ground state, causes the single electron's spin to act as a very sensitive magnetic probe with extraordinary spatial resolution.

Using the nitrogen center as an intermediary, a single carbon-13 atom's nuclear spin is cooled to near absolute zero, creating in the process a single, isolated quantum bit with a coherence time that approaches seconds. The controlled interaction between the electron and nuclear spins allows the latter to be used as very robust quantum memory.

The Harvard physicists also observed and manipulated coupling between individual nuclear spins, thus demonstrating a way to increase the number of qubits working in the quantum register. Because the electron spin and nuclear spin are controlled independently, the experiments lay the groundwork for development of larger, scalable systems in which such quantum registers are connected via optical photons.

"Beyond specific applications in quantum information science," the authors write, "our measurements show that the electron spin can be used as a sensitive local magnetic probe that allows for a remarkable degree of control over individual nuclear spins."

Source: Harvard University