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Qubits in the quantum sea

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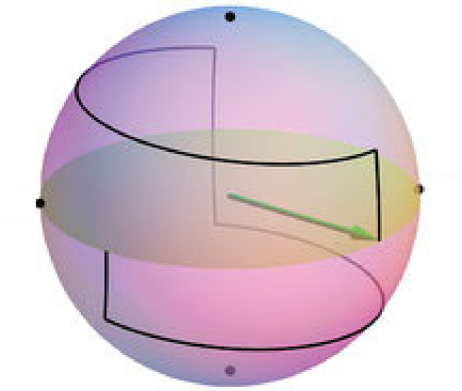


A “Bloch sphere” depicting the manipulation of of a qubit. Here the green arrow represents the status of the qubit as it undergoes a five-step controlled transformation consisting of three vertical movements (changes in “latitude” on the sphere) and two horizontal swings (changes in “longitude”). Credit: Xin Wang

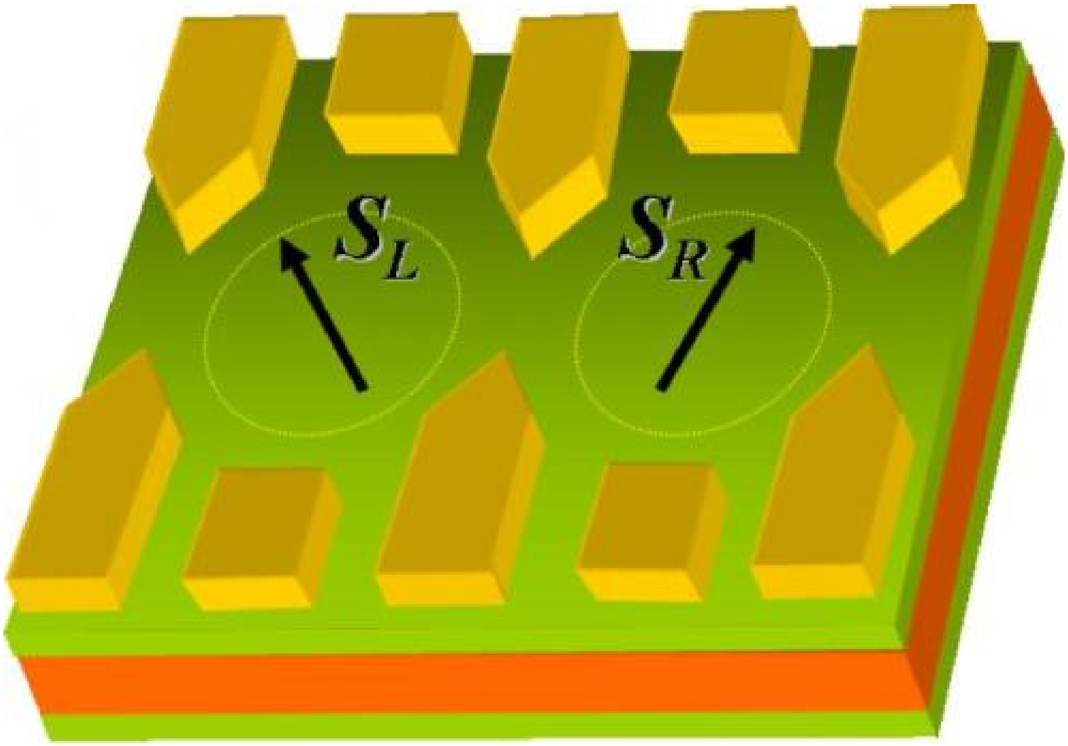
(Phys.org)—"Quantum weirdness," a phrase related to the power and the un-intuitive nature of quantum reality, is expected to facilitate speeded-up computation—quantum computing—for performing certain specialized tasks, such as factoring numbers. One drawback is that quantum computing depends exquisitely on the parts of a quantum system remaining coherent long enough—even in the face of environmental noise—for the computation to be performed. A proposed scheme should be helpful in sustaining coherence by carefully making mid-calculation corrections.

The new method is offered by Sankar Das Sarma and his colleagues at the Joint Quantum Institute and the University of Maryland, and is published in the journal *Nature Communications*.

One of the greatest contrasts between classical and quantum computing, namely the nature of stored information, can be depicted in geometrical form using a "Bloch sphere," named for physicist Felix Bloch. In a classical digital computer a unit of information, a bit, can have a value of either 1 or 0, corresponding to the north and south poles on the sphere. Meanwhile, a quantum unit of information, or qubit, can be a 1 or a 0 at the same time; to be more precise it is said to be in a superposition of the pure 1 state and 0 state. The status of the qubit can consequently be represented as points all over the sphere's surface.

Manipulating a bit in a conventional computer, by turning a 1 into a 0, is easily accomplished millions of times per second in laptops and smartphones using established technology in microchips. Manipulating qubits will be much trickier and (at least for now) subject to many hazards. One hazard is that the qubit itself will fly apart; that is, that parts of the quantum system constituting the qubit will no longer cohere. Another hazard is that in steering a qubit around the surface of a Bloch sphere it won't end up quite where you want it to be.

The JQI/Maryland research addresses the second of these hazards, and it does so for qubits maintained in quantum dots, tiny semiconductor domains which house one or two electrons. Quantum dots are one of the leading candidates for "hosting" qubits because scientists believe that the dots can be mass produced cheaply using mature nanotech assembly techniques.



Double quantum dot. In a semiconductor sandwich (green and orange layers) an essentially two-dimensional lake of electrons can be manipulated by voltages applied to a series of electrodes (yellow objects). For just the right voltage levels the lake can become a dot or island containing just one or two electrons. In this image a pair of electrons (configured to be a qubit) resides in each of two such dots (white circles). The spin of each electron is depicted by the black arrows, L and R corresponding to left and right. Credit: Vitaly Golovach via Wikipedia

In quantum dots a qubit typically consists of two electrons, whose magnetic properties (in the form of a fixed value of "spin") can be correlated. The electrons and their spins are under the control of forces exerted by nearby electrodes and micro-magnets.

Just as one wants to be sure of a bit's value when information is stored in a conventional memory unit, in quantum computers you want to be sure of a qubit's value when storing and processing quantum information. In a quantum dot, qubits can be steered around the z axis of the Bloch sphere (in an east-west direction—-the equivalent of longitude) when the interaction of the two electrons is modified by tweaking the voltages on the electrodes used to hold the electrons in place. Qubits can be steered around the x axis (in a north-south way, the equivalent of latitude) by changing the magnetic field gradient of (for example) a nearby micro-magnet.

It's important to know where the qubit is on the Bloch sphere; much effort is being applied to this problem since reliable quantum processing of information depends on this. This is analogous to the effort made, centuries ago, to locate longitude at sea reliably since shipping and exploration depended critically on knowing where you were.

Problems can arise when you lose precise control over the qubit's whereabouts. Stray magnetic fields, for example, can cause a qubit's orientation to be improperly swayed. An imperfection in atoms in the crystal might be the problem, or the spins of the nuclei of the atoms making up the semiconducting sample (gallium and arsenide atoms) can fluctuate slightly. Fluctuations of as little as 5% in the strength of the local magnetic field can throw off quantum calculations involving the qubits.

Xin Wang, one of the authors of the paper, compares the manipulation of qubits across a Bloch sphere to an airplane journey from Hawaii to New York. A 5% error in navigation can result in a 230-mile mistake: the plane arrives in Boston or Washington.

"Our idea for correcting this is simple," says Xin Wang. "We let the error correct itself. The good thing in our system is that the direction of the drift is opposite between 'east' and 'west' hemispheres. So that when some drift happened in one hemisphere, we can ask the qubit to rotate all the way around the other hemisphere so that there would be drift in the other direction, leaving room to correct errors. There is no law saying one must take the shortest flight on a Bloch sphere: one may travel around the sphere several times before it ends up with the desired position. It is this fact that one may travel around the sphere several times, and that drift happens in opposite direction on different hemispheres, that makes error correction possible."

In other words, the proposed new error-correction scheme uses a series of electrical pulses applied to those electrodes to get the qubit to fly all the way around the (Bloch sphere) world, if necessary, to arrive at its proper destination. Xin Wang again: "Suppose we want to fly from Honolulu to New York City. When we think we could arrive at New York City, we realize that we are just flying over the White House. Then what do we do? We continue flying. On the other side of the earth we should fly slower so that there would be more drift on our route. Then when we come back to Hawaii we do not fly over Honolulu, but around 230 miles to the north of that. Then we change our speed back to that in our original segment, we would actually land at New York City."

The JQI scientists have made two short videos, one that shows what happens to a drifting qubit without any correction, and one with the correction process (see below). They expect that their correction scheme can be tried out quickly in quantum-dot experiments.

More information: Wang et al, "Composite pulses for robust universal control of singlet-triplet qubits", *Nature Communications* 3, 997 (2012); doi:10.1038/ncomms2003

Provided by University of Maryland

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